IMPROVING LABORATORY LEARNING OUTCOMES: AN INVESTIGATION INTO THE EFFECT OF CONTEXTUALISING LABORATORIES USING VIRTUAL WORLDS AND REMOTE LABORATORIES

A thesis submitted in fulfilment of the requirements for the
degree of Doctor of Philosophy in the School of Information Technologies at
The University of Sydney

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August 2016

Dedicated to Claire Celli, loved and missed

Statement of Original Authorship

I declare that the research presented here is my own original work and has not been submitted to any other institution for the award of a degree.

I certify that the thesis has been written by me and that all the assistance received in preparing this thesis and all sources have been acknowledged.

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Abstract

This thesis presents research into improving learning outcomes in laboratories. It was hypothesised that domain specific context can aid students in understanding the relationship between a *laboratory* (as a proxy for reality), the *theoretical model* being investigated within the laboratory activity and the *real world*. Specifically, the research addressed whether adding domain context to a laboratory activity could improve students' ability to identify the strengths and limitations of models as predictors of real-world behaviour (a recognised laboratory learning outcome). The domain context was included in a laboratory activity with the use of a remote laboratory set within a context-rich virtual world.

The empirical investigation used a pretest-posttest control group design to assess whether there was a statistically significant difference in the learning outcome between a treatment group who completed the laboratory in the contextualised virtual world, and the control group who conducted the same activity in an empty virtual world. Undergraduate radiography students completed the remote radiation laboratory investigating the inverse square law of radiation intensity at a distance. There were 80 valid individual responses, 44 in the treatment group and 36 in the control group. The results from the empirical study showed that there were no statistically significant differences between the groups. The research has shown that there are cases where contextualising a laboratory activity will not have an effect on students' ability to identify the strengths and limitations of models as predictors of real-world behaviour.

This research postulates that the cohorts' previous exposure to a laboratory investigating the same model may have masked the effect of the context provided in the study: both the control group and treatment group had access to context generating information and the additional information provided in the lab activity was not sufficient, or possibly interactive enough, to change students understanding significantly. Another possible explanation is that the timing of the posttest meant that students did not have time to reflect on the activity, and so the effect of the additional context was not yet evident in the study measurements.

This research has contributed a framework for the analysis and design of domain context in laboratory activities, and an interface for integrating iLabs laboratories into the Open Wonderland virtual world. It has explicitly clarified the relationship between context, labs, models and the real world. Most significantly, this research has contributed knowledge to the field of laboratory learning outcomes and the understanding of how domain context affects laboratory activities.

Acknowledgments

Undertaking this PhD has been a life-long ambition and I have thoroughly enjoyed the experience. It would not have been possible to do without the support and guidance that I received from participants, friends, supervisors, experts and family who all deserve to be thanked and acknowledged.

Foremost, I would like to thank my supervisor Prof. David Lowe. He has made an incredible contribution to my PhD in terms of his time, knowledge, guidance and support through the process, from the very beginning. His advice, insights and enthusiasm for research were a huge motivation and his patience invaluable, especially during the tougher times in this PhD pursuit. I have been extremely fortunate to have him advise and mentor me and I believe he has helped me get the most out of this PhD experience.

I would also like to thank my co-supervisor, Christian Gütl who helped with focusing the ideas for this research and provided his guidance and assistance generously.

I am indebted to those who helped me with the technical details, and gave input and support through the development of the tools for the thesis, especially Mark Schulz and Len Payne for their assistance with the University of Queensland remote laboratory, and to Gary Tuck for his input on assessment and use of the lab. Thanks to all those on the Open Wonderland Forum for your responses and solutions. Also, for administrative and technical support, thank you to Evelyn Riegler and Greg Ryan.

Thank you to Dr John O'Byrne who was incredibly accommodating in allowing the research to be conducted with his students, and provided insightful feedback on the study. Also to the tutors who helped run the laboratory sessions, and to all of the participants.

I acknowledge the financial support awarded by the Commonwealth Government and the University of Sydney (as well as the University of Technology, Sydney where I began my research) through the Australian Postgraduate Award.

I am incredibly thankful for the love and encouragement of my father, Gabriele, who provided my first example and the inspiration for my PhD ambitions, and my mother, Claire, for the incredible belief that I could achieve anything I wanted to - I am sorry you are not able to see this completed. Also, to my mother-in-law, Myrna, for providing a further example that this PhD is what I wanted to achieve, and along with my father-in-law Mike, a huge thank you for all the support (not least in child minding) that you have given over the years this PhD has consumed.

I am grateful for my sister and other wonderful friends, near and far, who provided light relief and conversations that were not about this work - I needed them! And for those who did endure the PhD conversations, thank you even more.

Lastly, to the most important people in my life - Alan, Ben and Toby - for their patience, support, wonderful distraction and unconditional love. Boys, you did a brilliant job growing up so beautifully while Mum was often distracted. Alan, you are my best friend, the ideal sounding board, my greatest champion, an excellent barista and the perfect partner. Al, your contribution made this possible ... now for mine. Thank you!

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Glossary

Terms used within this thesis that have either been defined here, or do not have standard definitions, as well as the abbreviations used are listed here for clarity.

3D	Three-dimensional
AAPT	American Association of Physics Teachers
ABET	Accreditation Board for Engineering and Technology
API	Application processing interface
Context framework	A framework developed in this thesis that guides the analysis or design of context in laboratory activities
Domain context	Those elements of context which are specific to the content under study
iLabs	A project that has developed a laboratory sharing platform for remote laboratories
ISA	iLabs Shared Architecture
Lab Client	A component of the iLabs architecture that provides the interface to the operation of the lab
Lab Server	A component of the iLabs architecture which is operated by the laboratorys owner and deals with the actual operation of the lab hardware
LabShare	A consortium supporting remote laboratory sharing. LabShare shared remote laboratories primarily use the UTS developed Sahara lab sharing platform
LMS	Learning management system
LSL	Linden scripting language (the scripting language used in Second Life and supported by OpenSimulator)

MIT	Massachusetts Institute of Technology
MMO	Massively multi-player online games
NRC	National Research Council
Open Wonderland	An open source virtual world developed by Project Open Wonderland
PhET	Physics Education Technology
REST	Representational State Transfer, a simple stateless architecture that generally runs over HTTP
Sahara	The laboratory sharing platform developed by the LabShare consortium
SDCA	Story-Driven Contextual Approach (Klassen's (2006) approach to context)
Service Broker	A component of the iLabs architecture, which mediates exchanges between the Lab Client and the Lab Server and provides storage and administrative services that are generic and can be shared by multiple labs within a single site
Situational context	The environment (physical, personal, social, technological etc.) in which the laboratory is being conducted. The situational factors are independent of the specific laboratory being conducted.
SOAP	A protocol specification for exchanging structured information in the implementation of web services, originally an acronym for Simple Object Access Protocol
UQ	University of Queensland
UTS	University of Technology, Sydney

Chapter 1

Introduction

This thesis presents the results of research into whether adding contextual information to a laboratory activity can be shown to improve students' understanding. This will be explored through considering the ability to identify the strengths and limitations of models as predictors of real-world behaviour.

This topic developed from a desire to improve learning outcomes in laboratories, and a recognition of the potential that technologies which are relatively new to education (such as remote laboratories and virtual worlds) present for enhancing and scaffolding laboratory activities.

This introductory chapter begins with a brief description of the initial interest in this field and then provides an outline of the existing problem this research aims to address. The research objectives are summarised and an overview of how this research was conducted is given. The significance of the research, as well as the contributions that have been made in completing it, are presented. The chapter concludes with a description of the structure of this thesis and the peer-reviewed publications that have resulted from this research.

1.1 Motivation

Laboratories have been used in teaching in the sciences for well over 100 years (Novak, 1976). However, the exponential improvements in technology, changing approaches in the understanding of cognition and pedagogy, and significant changes to the structure and composition of academic institutions and their students, have meant that many laboratories have changed significantly from the traditional 'hands-on' experiment in a science laboratory. Today's students are being offered a much wider range of experiences, they have more information available to them and a greater choice of how laboratory activities are presented. The increased focus into how laboratories can be delivered and the intended learning outcomes of laboratories are evident in the literature, but there is much scope to add to the existing understanding of how best to deliver these learning outcomes (Lindsay, Naidu, & Good, 2007; Lindsay, Murray, Liu, Lowe, & Bright, 2009; Hofstein & Lunetta, 2004; Feisel, Peterson, Arnas, Carter, Rosa, & Worek, 2002; Feisel & Rosa, 2005; Wofford, 2008).

This researcher's experience working on the development of a remote laboratory sharing platform (which allows shared access to real equipment from remote locations) brought to light the effort in a number of institutions worldwide developing new remote labs and expanding access to them. Remote laboratories are being extended to include collaboration tools, to improve sharing and to introduce flexible interfaces that allow for more rapid development, customisation and deployment. The iLabs remote laboratory group, for example, has explored a system to access remote laboratories through three-dimensional virtual worlds (Scheucher, Bailey, Gütl, & Harward, 2009). That project aims to investigate the potential for improved collaboration that can be delivered using a virtual world.

Discussions with academics involved in the field, and an interest in conducting research, led to consideration of what other advantages three-dimensional virtual worlds may present for enhancing laboratory activities. The ability of virtual worlds to provide considerable contextual information was identified as one such advantage that could have an effect on laboratory learning outcomes. The literature is clear that in many cases contextualising learning activities *can* affect learning outcomes. There are many examples of contextualised laboratories but no studies were uncovered which look specifically into the effect of the contextualisation on the laboratory learning outcomes. This provided the starting point for developing the hypothesis investigated in the research described in this thesis.

1.2 Research Problem

Laboratories are widely used across all education levels and a wide range of disciplines, where they are generally accepted as essential, or at least significantly beneficial, to student learning. Despite the almost universal assumption of the benefits, there is limited research into laboratory learning objectives or their effectiveness in achieving these learning outcomes (Feisel & Rosa, 2005; Hofstein & Lunetta, 2004; Corter, Nickerson, Esche, Chassapis, Im, & Ma, 2007). There is much scope to contribute to the understanding of how current laboratories meet identified learning objectives, and further, how laboratories may be used and designed to improve learning outcomes. This is a broad field of inquiry, and the subject should be investigated further to identify specific problems that research may address to contribute to the field.

Feisel et al. (2002) reported on a colloquium organised by the Accreditation Board for Engineering and Technology (ABET) which identified 13 learning objectives of laboratories, each of which presents a target for possible improvements. Among these objectives is a laboratory activity's ability to support an increased understanding of the relationships between theoretical models and the reality that those models are representing. Despite the fact that experts have identified the role of laboratory experimentation in developing a strong understanding of models, there has been only limited consideration within the literature of the relationship between laboratory experimentation and either model representation or model evaluation (Gilbert, 2004; Mäki, 2005). A students' understanding of a model, and the relationship it has to reality, has a substantial effect on their ability to use that model to reason about aspects of reality: the more they understand this relationship, the better they can use the model in new circumstances, and understand its strengths and limitations. Science and engineering graduates are expected to be able to apply the theoretical knowledge to real world circumstances, and the clear understanding of the nature of models and their relationship to the real world is fundamental to such knowledge transfer. The consideration of this three way relationship between models, the laboratory and reality presents an interesting focus for research into improving laboratory outcomes. The problem exists of understanding how this model-laboratory-reality relationship can be better illuminated for students within laboratory activities and whether this would subsequently lead to an improvement in learning outcomes.

A potentially important aspect not addressed within the research literature on laboratory learning outcomes relates to the role of context. There has been substantial broader research that argues that the context in which concepts are presented can have a major affect on the learning of those concepts (Godden & Baddeley, 1975; Smith, Glenberg, & Bjork, 1978). Despite this, the role of context in laboratory education has been largely left unconsidered. In a 'traditional' laboratory environment, while laboratory guides provided to students might provide some context (such as an illustrative scenario) the laboratory apparatus itself is often sitting on a stark lab bench removed from the context in which the concepts being studied might exist in reality. While it can be argued that this may be an advantage (perhaps removing distractions allows a focus on the core elements of the experiment), there is little evidence of the consequences of this context-free presentation. The question that results from this is whether contextualising the laboratory might impact laboratory learning outcomes. Context can be used to provide a link between the laboratory, the content under study in the lab and the real world environment in which the concepts must ultimately be understood. It can be argued that context may be the instrument that clarifies the model-laboratory-reality relationship.

At a high level the research problem being addressed here is how laboratory learning outcomes may be improved. Narrowing the focus has identified a learning outcome in which improvement will have substantial effects on graduates being able to apply theoretical knowledge to the real world. Specifically, this thesis addresses the problem of how to improve students' understanding of how models, investigated within a laboratory, relate to the real world. The research considers whether contextualisation of the laboratory activity can improve this learning outcome and thereby contribute to the educational value of laboratories.

1.3 Research Overview

This thesis describes the research conducted to address the identified research problem of improving learning outcomes for laboratories.

To understand the current knowledge in the field, a literature review using both an adhoc and systematic review process was conducted. This provided the background theory for the research and identified a number of significant key concepts and definitions useful in describing the research. The review focused on research into learning in the sciences and its connection with laboratories, models, context and virtual worlds. The literature review led to the identification of a specific gap in knowledge from which the research problem could be identified, namely that it is not known whether adding domain-specific contextual information to a laboratory can improve students' ability to identify the strengths and limitations of theoretical models as predictors of real-world behaviours. The literature review also identified a feasible tool that could be used to test this scenario: a remote laboratory accessed from within a virtual world supplemented with contextual information.

Having identified a gap in the knowledge, a hypothesis was developed. The hypothesis was deconstructed and a number of research questions were derived. Research methods were selected to address the questions and test the hypothesis: the literature review; the development of the necessary research tools (namely, the context framework and test platform); and an empirical investigation.

The literature review provided no clear method for determining what would constitute suitable contextual information for laboratories. Consequently, as part of this research, a contextual framework was developed from a synthesis of current ideas on the nature of context, its function, presentation and effect. The framework was developed as a tool to provide a structure and process for analysing existing contextual information in laboratories and for designing new, suitable context for the laboratory used in this research.

The platform developed as a tool for presenting the contextualised laboratory to students was an integrated remote lab and virtual world. A comparison of virtual worlds was done to determine which was most suitable for this research and possible future work in the area. Similarly, a range of remote laboratories and their underlying models were compared to determine which would be best suited to this research.

The empirical investigation used a pretest-posttest control group research design to gather information from a cohort of undergraduate students who were required to understand the selected model and its relationship to reality. The research also included a qualitative research questionnaire used to gather information about students' perceptions and attitudes towards the activity and to identify possible avenues for future work. Quantitative data obtained from executing the investigation was gathered and statistically analysed to test the null hypothesis.

The results were analysed in light of the existing knowledge in the field and the specific circumstances of this research study, and conclusions were drawn. These conclusions, along with the knowledge gained through conducting the research, provide a contribution to existing knowledge and identify avenues for future research that may further contribute to improving laboratory learning outcomes.

1.4 Research Significance and Contributions

The objective of this research is primarily to contribute new knowledge to the field of laboratory learning outcomes.

The scope to improve learning outcomes in laboratories is large, with little research having been reported which addresses specific learning outcomes. The effect of improved learning outcomes is significant to educators and students. Much money and time is spent in the development, provision, maintenance, and execution of laboratories and improvements to learning outcomes will add to their value. This research has contributed to the understanding of how these learning outcomes may be improved, and given an indication of where future work may focus to provide additional justification for the investment in labs.

This research targets specifically the understanding of models as predictors of real-world behaviours that is developed within a lab activity. Students are required to understand this relationship in order to apply the theory they learn in their studies to real world problems they will encounter. If students can improve their ability to identify the strengths and limitations of models, the benefits will extend over the course of their education, and into the application of models in other spheres. Students with a better understanding of this relationship may perform better at real world tasks based on these models. The relationship between the model, laboratory and reality is core to developing this understanding and this research has contributed to clarifying the model-laboratory-reality linkages. The research outcomes contribute to the development of student competencies for this learning outcome.

An analysis of the literature found that there is limited discussion of domain-specific context for laboratories. In completing this research, a framework was developed from concepts in the literature that facilitates the analysis and design of domain context in laboratory activities. This has contributed a new approach to understanding the nature and function of domain context in laboratory activities. The application of the framework in a case study for an existing laboratory and to new context design in this research has provided a foundation for illustrating its usefulness and has provided an avenue for future research into its applicability.

The emergence of new technologies means there are new opportunities to influence how laboratories are presented to students, how they experience labs or interact within lab activities and how laboratory outcomes are assessed. While the choice exists to use new tools, it is important to understand whether they have any effect on learning outcomes and whether changing existing laboratories can be justified as adding value to students and educators. In developing the test environment for this research the feasibility of conducting a remote laboratory in a virtual world will be shown. Results of this research contribute to the knowledge on the effectiveness of a new technology on the targeted learning outcome. Outcomes provide an indication of where future research into the use of virtual worlds and remote labs should head in order to improve lab outcomes.

Most significantly, the research results achieved here deliver new information on the effects of contextualising laboratory activities and contribute to existing knowledge on the improvement of laboratory learning outcomes. The results of the empirical study contribute new information on how students learn from lab activities, and the effect that contextualising laboratory activities may have on their learning.

1.5 Research Publications

During the course of this research, the following co-authored papers relevant to this research have been published:

- Machet, T., Lowe, D. B., & Gütl, C. (2012). On the potential for using immersive virtual environments to support laboratory experiment contextualisation. *European Journal of Engineering Education*, 37 (6), 527-540. DOI: 10.1080/03043797.2012.721743.
- Machet, T. and Lowe, D. B. (2012). Integrating real equipment into virtual worlds. In L. Mann & S. Daniel (Eds.), *Profession of Engineering Education: Advancing Teaching, Research and Careers: 23rd Annual Conference of the Australasian Association for Engineering Education 2012, The* (pp. 195-205). Engineers Australia. Available from https://www.engineersaustralia.org.au/australasian-association-engineering-education.
- Machet, T. and Lowe, D. B. (2013). Issues integrating remote laboratories into virtual worlds. In H. Carter, M. Gosper, & J. Hedberg (Eds.), *Proceedings of the 30th ascilite Conference* (pp. 521-525). Available from http://ascilite.org/.

In addition the following co-authored paper has been accepted for publication:

- Machet, T. & Lowe, D. B. (in press). An analysis of the provision of context within existing remote laboratories. *Frontiers in Education 2015*.

Additional papers are planned to be drawn from this research and follow up work:

- An empirical study into the effects of contextualising laboratory activities. A paper publishing the findings from the empirical investigation done in this research and the conclusions drawn.
- Framework for the analysis and design of context in laboratories. A paper presenting the context framework, including case studies and further investigation of context in laboratories.

1.6 Document Structure

This thesis presents the research undertaken for a PhD commenced at the University of Technology, Sydney (UTS) and completed at the University of Sydney in the Faculty of Engineering and IT. The structure includes a number of preface pages, eight content chapters detailing the core work of the research and a number of appendices that contain relevant but more detailed information than required in the body of the thesis.

The literature review and the body of the thesis present the work done in completing the research thematically (rather than chronologically). Where applicable each chapter summarises the research questions that have been answered within the content of the chapter.

Preface. This section includes the title page identifying the document, a certificate stating authorship and originality of the content, acknowledgment of all assistance offered in the research and compilation of this document, a table of contents, lists of the tables and figures included in the document, a glossary of the terms used, and an abstract summarising the research.

Chapter 1: Introduction. The first chapter defines the research problem being addressed by the research, gives an overview of the research done and explains the significance of this research and its potential contributions to knowledge. The chapter also includes a list of publications generated by the research and outlines the document structure.

Chapter 2: Literature Review. The second chapter surveys and evaluates the relevant literature in the field and highlights the background theory that applies to this research. The chapter draws existing knowledge together to identify a gap in current knowledge and propose a hypothesis for this research. The chapter also includes a review of the research in areas that contribute to the thesis but do not form part of the development of the hypothesis.

Chapter 3: Research Approach. This chapter restates the research hypothesis and deconstructs it to find the research questions that must be answered by the research. A review of the literature concerning appropriate research approaches is done and the methods chosen to address the research questions are described and justified. The associated ethical issues are also discussed.

Chapter 4: Creating a Laboratory Context. This chapter begins with a description of the selection of the remote radiation laboratory for this research in order to provide the required background for the discussions on context. The chapter makes use of the information gained in the literature review to define what is meant by context in this research and it describes a framework developed specifically for the analysis and design of domain-specific context in a laboratory activity. The framework is applied to an existing laboratory as a case study in its use, and is then used to develop the context for this research investigation.

Chapter 5: Developing the Integrated Remote Laboratory and Virtual World. This chapter details the steps in the development of the integrated virtual world and remote laboratory environment that is used as the primary research tool for conducting the empirical investigation. The chapter summarises the relevant literature and justifies the selection of the virtual world platform used for this research. A detailed description of the final implementation is then provided.

Chapter 6: Empirical Investigation. The research method selected for the primary investigation is described in detail within this chapter. The design, selection, collection, and analysis of the data is presented here along with a discussion on the validity of the results. The results of the statistical analysis of the data is given.

Chapter 7: Research Findings and Discussion. This chapter discusses each of the research questions in light of the understanding obtained from conducting this research and the empirical investigation results. A discussion section relates the results back to the existing state of knowledge and identifies how this research has developed this area.

Chapter 8: Contributions, Future Work and Conclusions. The chapter begins with a summary of the research done. The contribution to knowledge resulting from this research is summarised, and its implications for the field are outlined. Potential avenues for future work which can build on this research are presented here and final conclusions on the research drawn.

Bibliography. Lists each reference cited within the text.

Appendix A: ABET Learning Objectives. A list of the 13 ABET defined learning outcomes for laboratories.

Appendix B: Hydroelectric Energy Case Study. The laboratory activity and assessment documents for the LabShare Hydroelectric Energy experiment investigating energy transformation.

Appendix C: iLabs Specifications. The messages implemented for the ServiceBroker API for communication between Open Wonderland and a dummy Service Broker.

Appendix D: Ethics Documentation. he following Participant Information Statements and Participant Consent Forms given to all students.

Appendix E: Pretest Assessment. The pretest assigned to all students.

Appendix F: Laboratory Guide. The 'Running the Laboratory' lab guide given to students for the remote radiation laboratory in Open Wonderland in this research.

Appendix G: Laboratory Assessment. The laboratory tasks and assessment given to students for the remote radiation laboratory in Open Wonderland in this research.

Appendix I. Raw Data. The collated data collected from the empirical investigation conducted in this research.

1.7 Chapter Summary

This chapter has provided an introduction to the research that is presented in this thesis. In summary:

- The research aim is to offer knowledge that can contribute to improved learning outcomes for laboratories.
- There is scope to improve the understanding on how students learn about models in laboratory activities, and contextualising laboratories presents a possible way to achieve this. Improving students' understanding of models' relationship to the real world would contribute significantly to the value that laboratories can add to student learning.
- In completing this research contributions will have been made to the understanding of the relationship between models, laboratories and the reality they represent. Additionally, a framework will be developed that can be used to analyse existing context and design new context for labs. The feasibility of a new integrated remote laboratory and virtual world platform will also be established.
- The thesis is argued in eight chapters and includes a number of appendices to support the argument.

Chapter 2

Literature Review

This chapter presents, evaluates and discusses the existing literature on the topics related to this research. It brings together the literature from a number of fields: learning in science in general and laboratories in particular; the role that models play in learning and how they relate to laboratories; the effect of context on learning; and learning within virtual worlds.

Each of these areas is reviewed by placing them within an historical context, analysing the accepted knowledge and approaches to the topic and discussing the credible points of difference among researchers. The review then distills the literature into a number of concepts central to this research and importantly, it identifies a gap in knowledge in the field.

As an outline, the review covers the following:

- *Laboratories.* The review begins by touching on the practice, goals and theories concerning learning within the sciences. Focus is then put on the role laboratories play in this learning. The various types of labs that exist are discussed in broad terms, with remote laboratories particularly being investigated in more detail. Attention is also focused on laboratory learning outcomes, how they are assessed and how they are discussed in the literature with regard to remote labs. Specific topics that require more in depth investigation are presented in this section including descriptions of selected remote laboratories and the architecture of the iLabs lab sharing platform.
- *Models.* The literature on models is reviewed broadly looking at how they are used in learning, particularly in the sciences. Types of models described in the literature are reviewed and the way researchers determine whether a model is correct is investigated. The relationship between models and laboratories is then explored in the literature.
- *Context.* The definitions of context are discussed, and the term ‘domain context’ is defined

to organise the discussion. The literature on how context may affect learning is presented, and a more detailed analysis is done of how context is related to content in the literature. Finally context is investigated in terms of how it is presented in laboratories and how it can be expected to affect laboratory learning outcomes.

- *Virtual Learning Environments.* The literature on virtual environments as a tool to facilitate learning is explored. Specifically, there is a focus on current laboratories within virtual worlds and an attempt to find a consensus on how delivering laboratory activities within a virtual world is best achieved. As background for later discussions, details on a number of virtual worlds are presented as well as the architecture of the Open Wonderland virtual world platform.
- *Chapter Summary.* The analysis of the literature on learning, models, context and virtual worlds is combined to identify a gap in knowledge that this research hopes to address. The research idea is placed firmly within the existing literature and its bounds defined by the gap in knowledge it is addressing.

The literature review provides the background information for the research project that will situate it's findings within the current body of knowledge. All the conclusions drawn from conducting this research are related back to the information presented in this review to illustrate the contribution and significance in light of the current state of knowledge.

2.1 Laboratories

> *The laboratory is where elegant scientific theories meet messy everyday reality.*
> *(Corter, Esche, Chassapis, Ma, & Nickerson, 2011, p. 2054)*

'Laboratory' is a term used for *learning activities based on observation, experimentation, investigation or testing* (Trumper, 2003). This is a broad definition that covers diverse activities such as fieldwork, practical experiments or simulations. Other definitions are similarly broad such as Hofstein and Lunetta's (2004) stating that a laboratories are 'learning activities in which students interact with materials and/or models to observe and understand the natural world'. A traditional laboratory activity will involve equipment, associated tasks and lessons, scaffolding material (such as pre-lab work), teaching aids (such as text books or a lab tutor) and a specific environmental context (such as its location, group set-up etc.).

This research began with interest in improving learning outcomes for laboratory activities. There exists an enormous amount of literature on how students learn, which factors affect learning outcomes, and how to improve learning in general, as well as more research addressing these topics for laboratories in particular. This section of the literature review focuses on the role laboratories play in science learning.

2.1.1 Learning in the Sciences

The literature on learning in the sciences is vast, written from the view of scientists, historians, psychologists, educational researchers and others. In order to situate laboratories within a broader context, the historical development of pedagogic and learning theory approaches to science education will be considered here.

2.1.1.1 The Practice and Goals of Science Education

Science as a subject has been part of formal schooling since the 19th century when scientists themselves campaigned for its inclusion alongside the humanities (DeBoer, 2000).

Edgar (2012) provides a summary of how social and political forces have shaped the attitudes to learning in general and science in particular since the early 19th century (with a focus on America). Formal education was initially based on recitation literacy for the college bound elite, where knowledge was considered to be gained through recitation of facts and learning was considered as abilities in reading, writing, and knowledge of languages such as Latin or Greek. By the end of the century, education had changed with the gradual acceptance that all youth should be educated to meet the changing needs of an increasingly industrialised world. In the early 20th century, in line with the change in wider society, schooling began to take the form of a type of mass product production line - viewing incoming students as raw materials to be processed to achieve the desired product. The effect of the world wars on the need for educated recruits who could read and, importantly, interpret and understand written material changed the requirements for learning away from this. The baby boom, space race, increasingly inclusive social attitudes and technical innovations continued to affect the attitudes and practice of science education through the 20th century.

DeBoer (2000) in looking at the history of the concept of scientific literacy, explains how initially science education was justified not only in terms of its practical application, but also in terms of the intellectual training it could provide to students. The idea that science education fostered independent thought and intellectual development was supported by academics such as Charles Eliot (president of Harvard University) and John Dewey (a philosopher and leading educational reformer).

As society changed, so did the goals of science education, with the focus shifting back and forth between the applications and utility of science in society, and science as a subject that fostered a more general understanding of the world and a way of thinking. According to DeBoer (2000) and Rudolph (2005), the early 20th century saw the shift toward emphasising the *utility of science* within science education. In America, this was in line with the Seven Cardinal Principles for guiding education (published in 1918) which were 'health, command of fundamental processes, worthy home membership, vocation, civic education, worthy use of leisure, and ethical character' (Edgar, 2012, p. 2).

The developments during the world wars and following years saw an increasing interest in the strategic and security roles science played in society and this informed attitudes to science education. With the rapid advance in science and technology, the goals of science education were re-assessed and the concept of developing a 'scientifically literate' population emerged. Changing again, in the 1950s science education moved away from teaching about technology and back towards the principles of science. By the 1960s most science courses in America consisted of teaching abstract models and disciplinary knowledge rather than a pedagogy that developed independent thought. The rest of the century saw the balance move back and forth between the views that science education should be focused on content knowledge (separate from its application in society) and the viewpoint that the emphasis should be on the relationship between science and society.

DeBoer (2000) provides nine statements that serve to summarise the learning goals of science that have developed through these changing attitudes to science education and changing meaning of scientific literacy:

'1. Teaching and learning about science as a cultural force in the modern world...
2. Preparation for the world of work...
3. Teaching and learning about science that has direct application to everyday living...
4. Teaching students to be informed citizens...
5. Learning about science as a particular way of examining the natural world...
6. Understanding reports and discussions of science that appear in the popular media...
7. Learning about science for its aesthetic appeal...
8. Preparing citizens who are sympathetic to science...
9. Understanding the nature and importance of technology and the relationship between technology and science...' (DeBoer, 2000, pp. 592-593)

Clark, Nelson, Sengupta, and Angelo (2009) summarise four 'strands' which were identified as goals for science learning by the National Research Council (NRC) and which align with a number of other perspectives: conceptual understanding (understanding of science concepts and content); process skills (for gathering, creating, and processing knowledge), epistemological understanding (understanding the nature and development of knowledge) and attitudes and identity as regards their participation and engagement in science.

As well as affecting the goals and practice of science as described here, Edgar (2012) suggests that sociopolitical changes have been the drivers for the development of theories of learning which, along with the practices of teaching, have enhanced learning over the last centuries. The following section looks broadly at changing theories of learning.

2.1.1.2 Learning Theory

Theories on learning have developed significantly since a scientific understanding of the mind began to inform thinking. In the early 1900's (when more basic literacy was required from students) behaviourists' views dominated the psychology of learning. Behaviourism asserts that learning involves the formation of associations between stimuli and responses, with learning being attained when the proper response is given to a specific stimulus. Since then, there has been a rise in cognitive theories such as social-cognitive theory, information processing theory and constructivism. Cognitive theories emphasise the acquisition of knowledge and skills through the formation of mental structures and by processing information and beliefs. Constructivism as an epistemology (developing from cognitive theories) rejects the idea that scientific truths exist and that their discovery by students constitutes knowledge, but postulates rather that knowledge is personal and subjective as it is 'constructed' based on beliefs and experiences. (Duit & Treagust, 1998; Schunk, 2012).

These differing epistemologies and learning theories have implications for educational practice as they vary on fundamental issues which affect learning. Schunk (2012) lists six questions which identify the critical issues in the theories. The different approaches to addressing each of these questions can be summarised as:

- How does learning occur?
  Behaviourists emphasise the role of the environment, while cognitive theories add the concept that how students process environmental inputs is critical to learning. Cognitive theories place a larger importance on student differences.
- What is the role of memory?

  Cognitive theories highlight memory as critical for learning, suggesting presentation of material in such a way that it can be organised, related to existing knowledge and remembered meaningfully. Behavioural theories usually give little attention to how memory is created or retrieved.

- What is the role of motivation?
  Behavioural theories use the same principles of stimuli and response to explain learning and motivation, while cognitive theories maintain that motivation will influence how information is processed but that motivation does not always lead to, nor is it required for, learning.
- How does transfer occur?
  Behavioural theories emphasise that transfer of knowledge to new situations relies on similarities between stimuli, while cognitive theories suggest that students need to understand how to apply knowledge in different settings before transfer occurs.
- Which processes are involved in self-regulation?
  Self-regulation refers to the 'process whereby learners systematically direct their thoughts, feelings, and actions toward the attainment of their goals'. For behavioural theories, self-regulation requires no new process over the stimulus-response process, while for cognitive theories there are a number of mental processes (such as learning strategies or the perceived value of the learning) which can affect self-regulation, provided that learners have a choice in affecting these.
- What are the implications for instruction?
  At a very general level behavioural theories are best suited to simpler forms of learning (such as multiplication tables) while cognitive theories may be more suitable for more complex learning (such as mathematical word problems) but each case should consider the type of learning that is required and where 'simple' and 'complex' concepts are included.

In general, Schunk (2012) suggests that '[b]ehavioral theories imply that teachers should arrange the environment so that students can respond properly to stimuli. Cognitive theories emphasize making learning meaningful and taking into account learners' perceptions of themselves and their learning environments'.

The different and changing approaches found in learning theory as well as the practice and goals of science learning in general is relevant for the discussion on how laboratories, models and context are used in science education. Literature presented here serves as background information to the following discussions and underpins the development of the hypothesis on how educators can affect learning in order to improve laboratory learning outcomes.

2.1.2 The Role of Laboratories in Science Learning

Formal education began thousands of years ago and schools of education have existed in China since the second millenium BC (Lee, 2000). In the West, the first schools developed as the early Greek philosophers began questioning the nature of the world and human existence. From the beginning, there has been debate about the nature of knowledge and the process of learning with early thinkers being divided generally into two schools of thought on epistemology: rationalism, which regards reason as the source of knowledge, and empiricism, which proposes that knowledge comes from sensory experience. (Ertmer & Newby, 1993; Lee, 2000; Edgar, 2012; Schunk, 2012).

Modern science writing in the West goes back to Copernicus and Galileo in the 1500's and 1600s (who made use of early Arabic astronomers' ideas (Huff, 2003)). Both Copernicus and Galileo were empiricists, observing nature and seeking explanations for phenomena in the relationships between objects (rather than as inherent properties of the objects themselves as previous thinkers had) (Novak, 1976). Francis Bacon continued this tradition and espoused his *methods*: that new knowledge can only be built through observing facts in nature and drawing broader generalisations, ignoring preconceptions (Novak, 1976; Rudolph, 2005).

The empiricist view of science was dominant in writings concerning approaches to science when science became part of formal education in the 19th century. The writings reflected Bacon's scientific method and proposed strict empirical prescriptions as the way to 'do science well' (Rudolph, 2005). Novak (1976) discusses how, while the scientific method was championed by scientists and educators, the teaching of science initially was no different from the teaching practiced for languages and humanities. It was the adoption of laboratories in universities as a method of instruction beginning in the 1880s that first exposed students to the scientific method. The teaching of inductive reasoning processes (used by scientists to justify the inclusion of science in schools) involved students conducting independent inquiry and investigations within laboratories (DeBoer, 2000).

Laboratory instruction was spearheaded by German chemist, Justus von Liebig and adopted by American universities championed by Johns Hopkins University, the Massachusetts Institute of Technology (MIT) and Harvard (Rudolph, 2005; Feisel & Rosa, 2005). In turn, high schools began adopting the laboratory approach in their science curricula. This was supported by the growing progressive education movement (led by John Dewey) which endorsed the 'scientific method' and 'learning by doing' epitomised with the use of laboratories (Rudolph, 2005; Feisel & Rosa, 2005). However, according to Rudolph (2005) a movement grew in America to eliminate laboratories from science teaching in order to make it more 'interesting' for students - this in response to a growing number of secondary school students and the emergence of applied psychology and its adoption by educators. A tension developed between the scientific method and the 'utility of science' with many seeing these as incompatible ideas that translated into different views as to the value of laboratories in science education. Hofstein and Lunetta (1982) state that opponents of laboratories in secondary schools argued (amongst other points) that emphasising laboratory work may lead to a narrow concept of science, and that laboratories in schools often did not relate to students' capabilities or interests.

As events in the world changed attitudes to science learning and learning theory (as described in section 2.1.1), so did they shape attitudes to the value of laboratory work in schools and universities. For example, in America the goal to get man on the moon meant increased funding for university science and engineering and the expansion of laboratories. The subsequent decline in funding and engineering program enrolments once the moon goal had been reached and America was fighting in Vietnam, led to laboratory courses being significantly cut back (Feisel & Rosa, 2005).

Following World War I, labs were used largely for fact finding to illustrate and verify information learnt from teachers and books. In the 1960s the role of laboratory work began to be justified once again in terms of their ability to promote scientific thinking through investigation and enquiry. Trumper (2003) summarises the purposes that labs fulfil as found in the literature of laboratory supporters up to the 1970s as falling into four categories:

- skills (hands on skills, enquiry skills, communication, critical thinking, problem solving etc.);
- concepts (the representation, discovery and application of concepts);
- the nature of science;
- attitudes (such as curiosity, objectivity, accuracy, and teamwork).

These echo the categories described by Clark et al. (2009) as the goals of science education developed by the NRC (in section 2.1.1.1) and those described by Gilbert (2008, p. 9). Hofstein and Lunetta (1982) list the classifications of laboratory goals of other authors that also agree with these categories. Both Hofstein and Lunetta (1982) and Rudolph (2005) conclude from their reviews that the objectives of laboratories matched those of science and engineering education in general. As such, laboratories, with their ability to support the learning goals of science and engineering, played a large role in the curricula of schools and universities at the time.

Trumper (2003) compares the changing purposes identified in the literature in the decades after the 1970's and concludes that, while there is agreement on the objectives regarding skills and abilities developed in a lab, there were no longer references to development of an understanding of concepts, the nature of science or attitudes to science. This change in the purpose of labs is reflected in the literature at the time which showed that the effect of lab work on these factors was uncertain (as reported in Rudolph (2005)).

As cognitive learning theories took prominence over behaviourist theory, support for laboratories could be found in the constructivist approach to learning. Constructivist theories imply 'that students require opportunities to experience what they are to learn in a direct way and time to think and make sense of what they are learning. Laboratory activities appeal as a way of allowing students to learn with understanding and, at the same time, engage in a process of constructing knowledge by doing science.' (Tobin, 1990, p. 405).

Additionally, 'social constructivism' proposed by Vygotsky supports the use of laboratories in constructing knowledge as they include social interaction, and integrate action and language in a learning situation (Corter et al., 2011). Corter et al. (2011, p. 2057) provide a summary of the recent views on constructivism and learning in laboratories and state that 'recent theories from education (cooperative learning and constructivism) and from cognitive science (on the situated and socially constructed nature of cognition) provide formal justifications for traditional lab practices, as well as a scientific framework to investigate questions related to mechanisms by which such learning occurs'.

Jona and Adsit (2008) support the use of laboratories in terms of the additional instructional context they supply: learning is improved if students are taught the same content in a number of contexts.

2.1.3 Laboratory Learning Outcomes

The discussion above has shown that, while laboratories have been used in formal science teaching for well over 100 years, the justification for their use and the teaching goals associated with them have changed significantly over that time in line with the changing approaches to and goals of science education.

It is important to understand the outcomes that educators hope to achieve through the use of labs, and whether these outcomes are being met. Systematic reviews of the research suggest that literature on lab learning outcomes often fails to show a relationship between laboratory work and student learning (Hofstein & Lunetta, 2004; Hofstein & Mamlok-Naaman, 2007). In their 1982 review Hofstein and Lunetta concluded that '[t]he research has failed to show simplistic relationships between experiences in the laboratory and student learning' (p. 212) and in Hofstein and Lunetta (2004) they indicate that in the 20 years between their reviews (1982-2002), the potential that laboratories have to help students construct concepts had not been realised. Hofstein and Lunetta's (2004) review identifies a number of factors that affect student learning in labs:

- laboratory activities described in lab guides do not sufficiently engage students in the process on investigation (rather they are 'cookbook' lists of tasks);
- assessment of practical skills and knowledge gained are not given enough attention;
- there are discrepancies between teachers' understanding of what is required and 'best professional practice' that affects students' perception of the value of lab activities;
- limitations such as time and technical resources, limit teachers abilities to develop and implement appropriate inquiry-based activities.

In summarising research findings on 'practical work', Gilbert (2008, pp. 8-9) includes the following limitations that apply to learning from laboratories:

- 'there is a lack of clarity over the purposes of much practical work;'
- 'because of the ambiguity over purposes, practical work can sometimes hinder the development of an understanding of scientific ideas;'
- 'the development of transferable skills through practical work is doubtful;'
- 'some aspects of practical work are problematic for students, particularly the control of variables and judgment about data reliability;'

In order to achieve a laboratory that can meet learning goals, Jenkins (2007) suggests that laboratories be designed with clear learning outcomes in mind as well as be thoughtfully included along with classwork, attempt to integrate science content and processes and allow reflection and discussion. The question then, is to define what exactly the learning outcomes and purposes of laboratories are.

Hofstein and Lunetta (1982) identify a number of learning goals proposed by researchers that, as discussed above, agree very closely with the goals for science learning in general. They stress however, that since laboratories provide a unique mode of instruction, goals that are specific for labs should be developed. In their follow up review (Hofstein & Lunetta, 2004) they acknowledge that there was an increased focus on learning goals reflected in the literature but gave no learning objectives specifically for laboratories.

A report on the status of laboratory work in science in Europe included, as one of its goals, the identification of learning objectives for laboratory work (Séré, Leach, Niedderer, Psillos, & Vicentini, 1998). The approach taken involved a survey assessing teachers' objectives for lab work and the report concluded that three broad objectives were identified as the most important by teachers: for the student to link theory to practice; for the student to learn experimental skills; and for the student to get to know the methods of scientific thinking.

Trumper (2003) provides a history of laboratories in physics education. Of interest is the observation that one of the shifts in the focus for the goals of laboratories occurred with the growing acceptance of constructivism, particularly social constructivism proposed by Vygotsky. Based on these principles, the American Association of Physics Teachers (AAPT) published a set of goals for physics laboratories in 1997:

‘1. Goal 1. *The art of experimentation*: The introductory laboratory should engage each student in significant experiences with experimental processes, including some experience designing investigations.
2. Goal 2. *Experimental and analytical skills*: The laboratory should help the students develop a broad array of basic skills and tools of experimental physics and data analysis.
3. Goal 3. *Conceptual learning*: The laboratory should help students master basic physics concepts.
4. Goal 4. *Understanding the basis of knowledge in physics*: The laboratory should help students understand the role of direct observation in physics and to distinguish between inferences based on theory and the outcomes of experiments.
5. Goal 5. *Developing collaborative learning skills*: The laboratory should help students develop collaborative learning skills that are vital to success in many lifelong endeavors [sic].’ (Trumper, 2003, p. 649).

Jona and Adsit (2008) list the goals developed by the NRC for high school laboratory programs which correlate closely to those above but include concepts on the nature of science and attitudes to science:

‘1. Enhancing *mastery of subject matter* [Goal 3];
2. Developing *scientific reasoning* [Goal 2];
3. Understanding the complexity and ambiguity of *empirical work* [Goals 1 and 4];
4. Developing *practical skills* [Goal 2];
5. Understanding the *nature of science*;
6. Cultivating *interest in science* and interest in learning science;
7. Developing *teamwork skills* [Goal 5].’ [emphasis and comparison added] (Jona & Adsit, 2008, p. 10).

In addition, the four principles for effective laboratory experiences are given as: clearly communicated purpose for the laboratory exercise; activities suitably sequenced within the curriculum (that is explicitly linked to what comes before and after); concept and process learning should be integrated; and they should allow for ongoing discussion and reflection (Jona & Adsit, 2008).

Feisel and Rosa (2005) address the lack of defined objectives specific to laboratories directly. They describe the historical developments that led to a 2002 colloquy that convened to determine objectives for assessing distance education engineering laboratory programs. The result was a list of 13 fundamental objectives for all engineering laboratories. Through completing labs within an engineering curriculum, students should be able to gain an understanding of instrumentation, models, experimentation, data analysis and design. Within labs they should be able to learn from failure, develop psycho-motor skills and sensory awareness, learn about safety, communication, teamwork and laboratory ethics. For the full details of these objectives, see Appendix A. Of relevance for this research is the laboratory learning outcome concerning models:

> ‘ *Models*: Identify the strengths and limitations of theoretical models as predictors of real-world behaviors [sic]. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.’ (Feisel & Rosa, 2005, p. 127).

The ABET objectives agree closely with the AAPT’s five objectives listed above as well as those identified in the European report, however they provide more detail and measurable outcomes. These objectives have been used within the literature as a framework to evaluate the effectiveness of laboratories and as a guide to research into improving labs (Ma & Nickerson, 2006; Lowe, Murray, Lindsay, Liu, & Bright, 2008; Gustavsson et al., 2009; Corter et al., 2011; Rashid, Tasadduq, Zia, Al-turkistany, & Rashid, 2012).

Generally, the educational objectives of laboratories may be classified into Novak’s (1976) three learning domains: the *cognitive* domain including instrumentation, dealing with models, data analysis, and design building capabilities; the *psychomotor* domain including the ability to manipulate the laboratory setup; and finally the domain of shared parts of *cognitive and affective* aspects including creativity, safety, ethics, communication and teamwork. Most laboratory activities cannot (and are not designed to) meet all of these learning objectives. Selecting which learning objectives will be targeted for a lab activity is essential in designing a suitable activity and assessing student outcomes.

2.1.3.1 Assessing Laboratory Outcomes

Having identified a widely accepted set of learning objectives for laboratories, it is necessary to look at how learning outcomes may be assessed for lab work. Historically, research has not satisfactorily assessed learning outcomes in laboratories (Hofstein & Lunetta, 1982; Tobin, 1990). In their more recent survey of labs Hofstein and Lunetta (2004) report that assessment has improved since 1982 with new techniques being developed and media used to assess student learning in laboratory activities, however there were still a number of unresolved problems such as an agreed assessment measure of students' learning.

Tobin (1990) states that assessing knowledge gained in laboratories is not simple (especially when assessing practical skills). Ma and Nickerson (2006), in their review of literature comparing hands-on laboratories, simulations and remote labs, emphasise (as one of three observations) that there is no standard criteria that is used across the literature to evaluate the effectiveness of laboratory activities. To help address this Nickerson, Corter, Esche, and Chassapis (2007), in developing a framework by which the relative effectiveness of different forms of laboratories can be assessed, identify three types of outcomes that can be measured in assessing lab learning outcomes: student test scores for subjects involving laboratory activities (particularly on those questions that test the knowledge content of the laboratory), laboratory assignment scores, and student preferences for the different labs. The framework also identified a number of factors they consider to have an effect on students' cognition (which together with their motivation will result in different learning outcomes): the individual differences in students; the real and perceived format of the laboratory; the social coordination structure and how this is implemented; the nature of the experiment and the experiment interface.

Constructivist learning theory requires that assessment of student learning be done in the context of teaching rather than (as is more typical in a classroom) separated from teaching such as an end-of-semester exam (Schunk, 2012). Further, Schunk (2012) suggests that from a constructivist point of view assessment of learning outcomes may not be possible with only true-false or multiple choice tests, but that this should be combined with more 'authentic' forms of assessment such as a discussing why the knowledge is useful in the world. Laboratory activities can accommodate this requirement by including assessment along with the actual learning activity and ensuring that questioning goes deeper than multiple choice questions.

2.1.4 Types of Laboratories

The definition of laboratories as *learning activities based on observation, experimentation, investigation or testing* covers a very broad range of activities and not all researchers agree on the classifications for the types of laboratories that exist. This discussion is limited to laboratories in science education, although labs are used in a wide range of disciplines.

Feisel and Rosa (2005), looking at engineering laboratories, distinguish between *development* laboratories (used by engineers to collect data in order to answer a specific question), *research* laboratories (where engineers use the laboratory to discover new knowledge) and *educational* labs. Educational laboratories are used by students to learn about existing knowledge that practicing engineers know and require.

Hofstein and Lunetta (2004, p. 31) consider science laboratory activities to be 'learning experiences in which students interact with materials and/or with models to observe and understand the natural world'. These include projects, investigations and practical activities done inside and outside the classroom as long as they are considered a formal part of the curriculum. Further, Hofstein and Mamlok-Naaman (2007) describe how laboratories may vary, covering activities which range from individual tasks to group projects, from highly structured 'cookbook' instruction labs to open-ended, inquiry laboratories or from short demonstrations to projects that span many weeks.

Leleve, Benmohamed, Prevot, and Meyer (2003) classify traditional laboratories according their 'closeness with real life situations' as either educational specific systems (which 'zoom' in on specific phenomena), realistic systems (often scaled replicas of equipment) or real systems (employing the 'real' equipment such as tool machines or industrial robots). Laboratories may also be classified in terms of the fields they are used in, or the educational stage they are used for. More recently however, discussion on the types of laboratories that exist focus on the changes that have developed in labs due to available technology. Many researchers categorise and compare laboratory activities by their mode of delivery: hands-on laboratories, simulations or remote laboratories (Feisel & Rosa, 2005; Corter et al., 2011; Nickerson et al., 2007; Ma & Nickerson, 2006).

Hands-on laboratories are the 'traditional' laboratory where students work individually or in groups in a physical lab environment and interact directly with laboratory equipment. According to Ma and Nickerson (2006), two factors characterise hands-on labs: all the equipment required for the laboratory is set-up; and the students performing the laboratory are physically present in the lab. Hands-on laboratories provide the students with a real-world interaction where they get to experience the ‘noise’ present when comparing theory and practice. However, these labs are expensive to build, house, maintain and conduct in terms of money and time (Ma & Nickerson, 2006).

Computing capabilities have allowed for students to do *simulation* laboratories where no real equipment is used but students interact with virtual entities which are designed to respond as real equipment would. Simulations have been used for years in training for risky environments (such as flight simulators) and provide the advantage of letting students visualise phenomena they cannot see in a hands-on lab, such as electromagnetic fields (Feisel & Rosa, 2005). Some of the arguments for and against the use of simulations found in Ma and Nickerson’s (2006) review were that: simulated laboratories can be argued to be more cost effective though others suggest that realistic simulations take a lot of time and money to develop; students can pause simulations to review and consider the experiment (and therefore learn as well as for hands-on labs) but, as the data is not real, students cannot learn by trial and error; advocates argue that simulations foster active learning but detractors suggest that simulations primarily teach students how to run simulations. In a review of the literature on the use of simulation, there is agreement that simulation *can* support and enhance selected learning outcomes (Akpan, 2001; Lee, Guo, & Ho, 2008; Corter et al., 2011). Lee et al. (2008, p. 462) argue that to be most effective, computer simulations should be designed to address ‘content based on detailed knowledge of students’ learning difficulties, encourage reflection, and provide prompts when students encounter problems’.

The third category of laboratories is the *remote laboratory* where students interact with real laboratory equipment but from a remote location - a ‘mediated reality’. There is a very wide range of remote laboratories, some with simple web based camera and control panels as the user interface, through to highly realistic virtual representations of real control and measuring equipment, to laboratories that are fully embedded within virtual worlds. Remote laboratories arguably present cost savings over hands-on labs by allowing sharing and increasing lab availability time, therefore increasing the utilisation of the equipment. Development costs of remote laboratories are often reported to be high (Lowe et al., 2009). (Remote laboratories will be discussed in more detail in section 2.1.5.)

Leleve, Arnous, and Prevot (2009) show, by means of a diagram, that these three classifications of laboratories exist on a spectrum. From the perspective of *reality* they range from ‘real systems’ to ‘simulated systems’, and concerning the *distance from the user*, they range from ‘local’ to ‘distant’. This is shown in Figure 2.1. The figure illustrates too, that hybrid labs can be created combining real equipment and simulations, as has been shown with examples in the

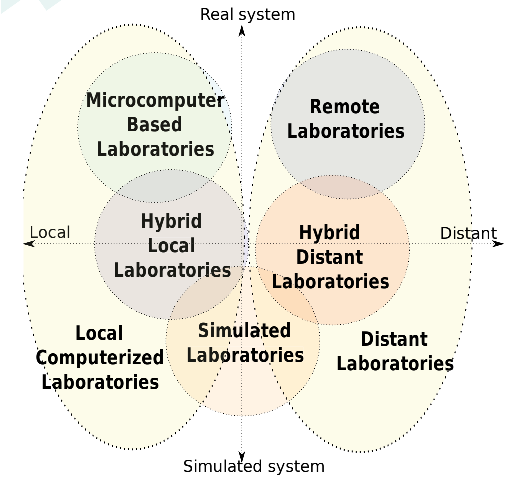


Figure 2.1: Types of laboratories classified by distance and reality of equipment (Leleve, Arnous, & Prevot, 2009)

literature such as the force on a dipole experiment being augmented with a field line simulation (Scheucher et al., 2009).

There is no agreement on which type of laboratory is ‘best’. Ma and Nickerson (2006), looking at the state-of-the-art for the three modes, conclude that there are supporters and detractors for each of the laboratory types. One reason suggested for the lack of agreement is that advocates of each mode measure against different criteria. Added to this, as technology improves, the boundary between these types of laboratories blurs: hands-on labs increasingly use equipment that is mediated by a computer for control; remote labs can include simulations as part of the presentation of laboratories.

2.1.5 Remote Laboratories

Of the three modes described, remote laboratories are the most recent, developing with the internet which has delivered the technology needed to remotely control real equipment. Remote laboratories began to be developed in the 1990s and have been increasingly used in a range of disciplines such as medicine, physics and engineering (Hahn & Spong, 2000; Nedic, Machotka, & Nafalski, 2003; Lindsay & Good, 2005; Trevelyan, 2004; Gravier, Fayolle, Bayard, Ates, & Lardon, 2008).

Aside from the technology advancements that have made these types of labs possible, the reasons for the increased use of remote laboratories (and similarly for simulations) is partially economic. Hands-on laboratories take laboratory space, and involve a time investment in set up and tear down each time they are used (Nickerson et al., 2007). In many cases, they are specialised for specific courses and so have limited utility and low utilisation (Lowe et al., 2009). Remote laboratories, however, take up less room, their set up and tear down processes are usually automated, they can be utilised 24 hours a day and do not require the same supervision as hands on labs. In terms of costs, they do however require significant development time, networking availability for users and some maintenance.

In addition to the potentially reduced costs, remote labs can give students access to dangerous experiments they normally would not be able to interact with. Remote labs can improve accessibility for those with disabilities or impairments and facilitate laboratory courses for distance education students. They can also allow for better utilisation by providing flexibility in lab scheduling and by taking advantage of the opportunity to share labs globally. (Lindsay & Good, 2005; Cooper & Ferreira, 2009; Lowe et al., 2009).

In their review, Gravier et al. (2008) look at ways to classify different types of remote laboratories. They describe most remote laboratories as following the same basic architecture: a device which is the laboratory equipment; a computer connected to the device which controls the lab; and 'middleware' which mediates between a users' remote computer and the local computer controlling the lab equipment. In terms of interfaces between the local computer and the device, there are no standard interfaces due to the huge range of devices and proprietary developments. They do however, mention attempts to standardise the interface such as Virtual Instrument Software Architecture. While less diverse, the interfaces between the local and remote computers also display large variation. These differences, they conclude, leads to limited reuse and interoperability between laboratories.

Early in the conceptualising of remote laboratories, the value of being able to share expensive resources was acknowledged (Abdulwahed, Nagy, & Blanchard, 2008; Ma & Nickerson, 2006). However, Gravier et al. (2008) suggest that in the years leading up to their publication, remote laboratories were developed individually with no concern for reuse or sharing. The literature has many instances of remotely operated experiments that describe their development and implementation but have no mention of the sharing potential of these laboratories (for example Trevelyan (2004); Hashemi, Chandrashekar, and Anderson (2006); Coito and Palma (2008)).

There are examples of lab sharing initiatives in the literature. Of interest are the groups who have developed the facility to allow widespread sharing of new and existing laboratories. Both the LabShare project (Lowe et al., 2009) and MIT's iLabs project (Harward et al., 2008) have developed sharing platforms (Sahara and the iLabs Shared Architecture (ISA) respectively) which allow remote laboratory developers to set up a lab which can be widely shared. These platforms have stable current releases, are currently in use around the world, have well defined interfaces for integrating new and existing laboratories and, for each of them, there is a wide range of different laboratory types currently utilising their sharing facilities. (The iLabs sharing platform will be presented in further detail in section 2.1.7.)

Other solutions to laboratory sharing include the Lila Project (Library of Labs) which aims to provide common entry point for a range of online labs (Richter, Tetour, & Boehringer, 2011) and other specifications and implementations of lab sharing platforms, standardised interfaces and integrations of laboratories into learning management systems that presently do not have as large an uptake as LabShare or iLabs (Leleve et al., 2003; Yan, Liang, Du, Saliah-hassane, & Ghorbani, 2006; Gustavsson, Zackrisson, Hå kansson, Claesson, & Lagö, 2007; Garcia-Zubia et al., 2010; Yeung, Lowe, & Murray, 2010; Marcelino, Silva, Alves, & Shaeffer, 2010; Richter et al., 2011).

The acknowledgment of the benefits that remote labs afford institutions and academics as well as their increased availability through the sharing of labs, has led to an increase in the research concerning their benefit to students. As applies to laboratories in general, the literature reiterates that while remote labs can be exciting, engaging and novel, educators must ensure that they are used as part of a pedagogic strategy (not simply because they can) and work must be done in evaluating their educational effectiveness (Cooper & Ferreira, 2009; Lindsay & Good, 2005). It is important to understand how the mode of the laboratory may affect learning outcomes when selecting a laboratory for use.

2.1.5.1 Remote Laboratory Learning Outcomes

Remote laboratories are not interchangeable with hands-on labs or simulations. Lindsay et al. (2007) identify two critical factors that define remote labs as different: the separation in space between students and the equipment; and the mediated interface to the experiment. The separation (both physical and psychological) changes how students perceive the laboratory experience. To overcome the separation, a mediated interface is used and the design and selection of this interface affects what student learn from the laboratory (effectively ‘biasing’ their experience). Not all modes of delivery are equally suited to meeting different learning objectives of laboratories (Lindsay & Good, 2005). The literature agrees that remote laboratories (and simulations) are not substitutes for hands-on experimentation, but rather should be they should be used in conjunction and only where the aims of the laboratory are best met using an alternative access mode (Lindsay & Good, 2005; Feisel & Rosa, 2005; Trevelyan, 2004; Trumper, 2003; Lee et al., 2008; Corter et al., 2011; Jona & Adsit, 2008).

Ma and Nickerson (2006) raise some issues that must be considered when using one mode over others. Specifically when considering remote laboratories, it is important to understand students' beliefs. Ma and Nickerson (2006) discuss literature that shows students' sense of presence is not merely determined by physical presence, but also by psychological factors that affect their perception of reality. They also identify that some argue that remote lab interfaces are distracting and often students do not believe the equipment is real so they are the same as simulations in many ways. The link between a laboratory task and the real world does not determine the effectiveness of laboratories alone. This is supported by Lindsay and Good (2005) and Sauter, Uttal, Rapp, Downing, and Jona (2013) who showed that students' perception of whether real equipment was involved in a laboratory activity affected their learning outcomes.

Care must be taken, therefore, when selecting remote laboratories that there is an understanding of how students *perceive* the equipment. Lindsay et al. (2009) explore the required fidelity and authenticity of simulations and remote laboratories and introduced the concepts of 'establishment reality' and 'maintenance reality'. Establishment reality is the threshold required for students to believe they're interacting with real equipment in a remote lab when it is first encountered. Maintenance reality is the threshold required to maintain this perception once the student is engaging with the laboratory and this will be a lower threshold.

Lindsay and Good (2005) describe two effects that the introduction of a new technology may have on learning outcomes: an amplification effect and an attenuation effect. Amplification refers to the positive effect that results from the technology's benefits (such as automation of tasks or faster calculations), while attenuation refers to the negative effects that result, often due to the user focusing on the technology itself rather than the learning content (the 'opacity' of the technology). Conclusions from that research identify that different access modes can improve certain learning outcomes, usually at the expense of others. Lindsay and Good (2005) caution that those teaching using a remote mode must compensate for the learning outcomes that are known to be hindered by the mode. Conversely, if a specific learning outcome is being targeted, it may be that remote laboratories are better suited to meet these outcomes. Nickerson et al. (2007) in developing the framework for assessing the relative effectiveness of hands-on labs, remote labs and simulations, also highlight that different lab forms are more suitable for different targeted learning outcomes.

In comparing learning outcomes in a remote laboratory to a simulation, Jona, Roque, Skolnik, Uttal, and Rapp (2011) conclude that the use of real equipment allows for 'more authentic inquiry'. They report that students trust the remote laboratory data more than the simulation and that they associate the real equipment with real error. This allows for the achievement of learning objectives that require identification and analysis of variation in data. Sauter et al. (2013) compared students completing a remote laboratory to those doing a simulation and found increased (and different) engagement for the remote laboratory students. They also identified students' perception of the reality of the equipment as an influencing factor.

Corter et al. (2011) report that remote laboratory research has focused on describing the labs and students' and teachers' perceptions of these labs, with a few looking specifically at learning outcomes when comparing remote labs to simulations or hands-on labs. In contrast to others, they conclude that in general the learning outcomes are equivalent for the different access modes but that students show different patterns of work and collaboration when engaging with the different modes, and these changes may lead to different learning outcomes. Ogot, Elliott, and Glumac (2003) too found no significant difference in learning outcomes for a study comparing remote labs to hands-on labs. In Lindsay and Good (2005) it is pointed out that there were the confounding factors of aggregation of a number of learning objectives and differences in lab supervision in the study by Ogot et al. (2003).

Bright, Lindsay, Lowe, Murray, and Liu (2008) comment on the lack of consensus in the literature as to whether remote labs make a difference to learning outcomes or not, and to which learning outcomes this difference applies. They look specifically at the factors that affect learning outcomes in remote laboratories, namely:

- students' understanding of laboratory procedures (such as setting up and taking down equipment) and the implications this has for the amount of 'time on task';
- social and instructional resources available to students;
- students' individual preferences for a specific laboratory format;
- the individual learning style of the student;
- students existing knowledge and prior experience;
- the amount of tutor assistance that is provided to students;
- changes in group work and collaboration within the laboratory activity;
- interaction between students and educators (closely related to collaboration, group work and tutor assistance);
- students' perception of the hardware;
- students' sense of presence.

They conclude that the focus on achieving learning outcomes should be on an awareness of each of these factors and not solely on the single dimensional variable of 'mode'. This is in agreement with Ma and Nickerson (2006) who conclude that research into laboratory effectiveness may be confounding the factors that influence learning outcomes in labs and instead attributing learning success to the mode of delivery.

The conclusions from the reviews on remote laboratories, simulations and hands-on labs suggest that their effectiveness is based on good pedagogic design, selecting a mode that suits the learning objectives being targeted, consideration of the social aspects of laboratory work (for example communication and teamwork), and students' and teachers' preferences.

2.1.6 Evaluating Remote Laboratories

For this research a test platform with integrated remote laboratory and virtual world is required to be selected or developed. For this reason, a number of possible options for the remote laboratory to be included in the study must be investigated. This information forms the basis for the later discussion and selection of the remote radiation laboratory used in this research (see section 4.1). In addition, the architecture of the iLabs platform is presented for background to the later technical development discussions (see Chapter 5).

Three potential laboratories were identified for this research study based on the importance for the laboratory to have a suitable underlying model that lends itself to the learning objective (these requirements are discussed in detail in section 4.1.1). These were the LabShare inclined plane experiment, the LabShare hydroelectric energy experiment and the iLabs remote radiation experiment.

Each of these laboratories is described here and will be compared in section 4.1 in terms of the suitability of the model, the ability to provide meaningful context, and lastly looking at whether any of the other requirements are limited by the choice of lab.

2.1.6.1 Inclined Plane Experiment

The inclined plane experiment at the University of Technology, Sydney is a remote lab accessible through LabShare's Sahara lab sharing platform. The lab consists of an inclined plane with a track that allows sliding blocks to move along it when it is tilted. Students can select the blocks (each of which have different materials in contact with the plane) and the angle of the plane. They are able to take measurements of the block positions, calculate their velocities and can therefore work out coefficients of static and kinetic friction, as well as calculation of acceleration due to gravity or calculation of the value of gravity. The laboratory equipment is shown in Figure 2.2.

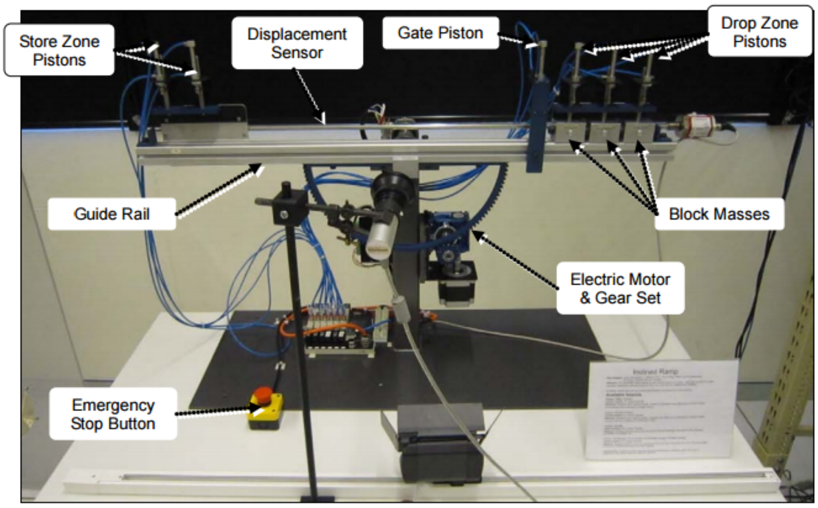


Figure 2.2: UTS Remote inclined plane laboratory equipment (obtained from http://www.labshare.edu.au/library/past_rigtypedetail/?id=3&version=1)

Looking specifically at acceleration due to gravity as the underlying model that can be investigated using this lab equipment, the model under investigation will have a number of strengths and limitations as a predictor of real-world behaviour that is not immediately apparent from executing the lab activity. The lab equipment highlights friction between the block and plane as a factor in acceleration calculations, however, air resistance as a source of friction and the effect that changing the shape of the block will have is not obvious. There are many applications of the calculation that can be inferred from the domain context inherent in the lab equipment but others that may be opaque to learners, such as the fact that acceleration due to gravity will apply to objects moving ‘upwards’ too.

The inclined plane is a laboratory for which there are existing lab activities and it has been used previously to target the model learning objective. Additionally there are a large bank of assessment questions available for the acceleration due to gravity model, particularly the Force Concept Inventory which includes Newtonian physics (Hestenes, Wells, & Swackhamer, 1992).

At first assessment, the LabView controller for the lab equipment will allow for the real equipment integration into a virtual world that supports application sharing (as done in Scheucher et al. (2009)). The interface to the laboratory provided for by the Sahara lab sharing platform is well documented and can be used in development of an integrated system. The reality of the lab can be established using the existing camera feed for the lab.

While the UTS inclined plane experiment had been previously used within the UTS Science faculty, planned upgrades to the rig mean that continued availability of the laboratory could not

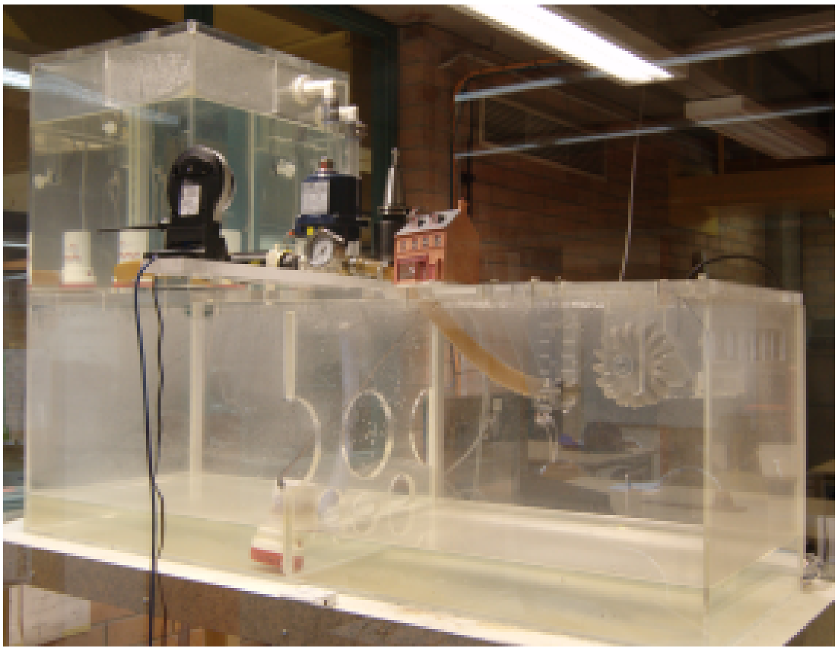


Figure 2.3: UTS remote hydroelectric energy laboratory equipment

be guaranteed throughout this research project.

2.1.6.2 Hydroelectric Energy Experiment

The LabShare remote hydroelectric energy laboratory is also hosted at UTS and accessed via Sahara. The equipment is pictured in Figure 2.3 and Appendix B contains an associated lesson plan. The remote laboratory can be used to study the principle of the conversion of kinetic energy of flowing water into electrical energy. The pump lifts water from a large lower tank to a smaller upper tank (to refill it when the level is low). A second pump has a user-controlled variable rate to force water through the monitored pipe and onto the cups of a Pelton wheel turbine at a rate proportional to the water flow rate. A generator connected to the Pelton wheel rotates at the same rate as the turbine and its electrical output is used to power the LEDs which can act as a monitor of power output, or as the load for the generator's output circuit depending on the laboratory lesson (Leung & Merrylands High School: Science Department, 2013).

The lab equipment is a simplified model of a hydroelectric power plant and using it to investigate the underlying theoretical model of energy conversion presents a number of strengths and limitations of the model as a predictor of real-world behaviour. While the physical equipment clearly illustrates the conversion of kinetic energy to electrical energy, the conversion that occurs within the generator is not obvious. Also efficiency calculations in possible lesson plans may imply that energy is ‘lost’ rather than converted to other forms. The lab equipment as a model includes a pump moving water from a lower to higher tank and while this is necessary for the functioning of the remote laboratory it does not accurately reflect the potential energy that dam water has and implies additional energy input into the system. One strength of the model is that it applies to all types of energy conversion.

Looking at the model from the domain context that is supplied allows the identification of the model house, the LEDs and the flowing water and gauges as domain context elements. There is however scope to further highlight the strengths and limitations of the model as many of these have not yet been addressed with the existing domain context. This experiment has been analysed as a case study on determining domain context in existing laboratories and will be detailed in section 4.4.

The laboratory has a number of cameras that can establish the reality of the equipment, it is being used currently for the teaching of models and there is the potential to access the laboratory directly from the virtual world or using the Sahara platform. The system is stable, available for use and there is support available from the developers and academics utilising the laboratory.

2.1.6.3 Radiation Experiment

The remote radiation experiment is located at The University of Queensland (UQ) and is accessed using a web-based, iLabs interface (Jona & Vondracek, 2013). UQ has its own interface that has been used to investigate radiation over a distance and (for a later version of the laboratory equipment) the effect of different absorbers on radiation intensity. Northwestern University has also developed its own interface for this laboratory which is used to teach experiment design to secondary school students (Sauter et al., 2013).

The equipment consists of a Strontium-90 source, moveable Geiger counter measuring particle count, and electronic controls that allow the user to operate the laboratory remotely. Users can control how far away from the source to move the Geiger counter, how long each measurement period should be and how many times the measurements should be repeated. This is shown in Figure 2.4.

The inverse square law for radiation intensity at a distance from the radiation source can be investigated using this laboratory equipment with a suitable lesson. The model describes how radiation intensity (in this laboratory measured by particle count) is inversely proportional to the square of the distance from the radioactive source.

Figure 2.4: UQ remote radiation laboratory equipment

At first analysis, the strengths of this model as a predictor of real-world behaviour are that the inverse square law applies to many other phenomena including gravity, light and sound and that as a predictor of radiation intensity from radioactive decay, this law works as a very good predictor in the long term. The limitations are that the effect of background radiation that will be present in the ‘real world’ measurement of radiation intensity (such as that from mobile phone towers, the sun etc) is not included in this model and the effect of absorption of radiation in the real world is not accounted for in the model and will have an effect on its ability to predict real-world behaviour. A further weakness is that radioactive decay is stochastic in nature so the inverse square law is an approximation to the radiation intensity rather than an accurate predictor. These are not obviously apparent from the laboratory equipment itself, and the link to the real-world behaviours can possibly be emphasised with the addition of contextual information.

The laboratory is accessed through an iLabs sharing platform which has a well-defined interface with access to source code so integration to real equipment is possible (Schulz, Rudd, & Payne, 2012). Once again, the lab has cameras that can establish reality (though the batching nature of this experiment means students may not be watching their own experiment executing). There is also an analogue clock that students can see moving while watching to emphasise that the video feed is live.

Interestingly for this research, the remote radiation laboratory is described in the literature as part of research into a high school physics curriculum with significant results on test scores and inquiry skills (Jona et al., 2011). It also formed part of a comparison between remote lab and simulation research, where it was found that the labs users were ‘more likely to feel and behave as though they conducted a real experiment’ and that the video supplied aided in engagement with the laboratory activity (Sauter et al., 2013).

The equipment is available along with support from developers of the lab and the academics using the lab. It has been used in learning activities with the understanding of models as one of the targeted learning outcomes. Additionally, both Northwestern University and the University of Queensland have their laboratory activities available online, providing a bank of tested laboratory material and assessment questions.

2.1.7 Existing Architecture: iLabs

iLabs is a remote laboratory sharing platform developed at MIT. Its origins date from 1998, beginning with the separate development of online accessible laboratories to help address the problem of expensive lab instruments, limited availability of space and the logistical problems that lecturers faced adding laboratory components to existing courses (Hardison, Delong, Bailey, & Harward, 2008). The MIT iLabs Project was eventually formed with the aim of developing a standard approach that could be used to combine the separate laboratories and provide a scalable system that allowed for easy deployment of new labs (Harward et al., 2008). The iLabs vision is to ‘share expensive equipment and educational materials associated with lab experiments as broadly as possible within higher education and beyond’ (*About iLabs*, ‘About iLabs’).

The result of this project has been the iLabs Shared Architecture (ISA). This is a broker architecture that allows for proxy agents to be managed by a Service Broker, thereby allowing these agents to be installed on different machines. At a high level iLabs consists of three components connected via a Web service architecture:

1. the *Lab Client* which runs on the end users computer and provides the interface through which the user creates and submits an experiment specification;
2. the *Lab Server* which sits with the laboratory owner and manages the operation of the hardware including the validation and submission of an experiment from the Lab Client (via the Service Broker) and running the experiment on the laboratory equipment;
3. the *Service Broker* which acts a a mediator between the Lab Client and the Lab Server providing shared services such as data storage and authentication services. A single Service Broker can support a number of Lab Servers (or different labs).

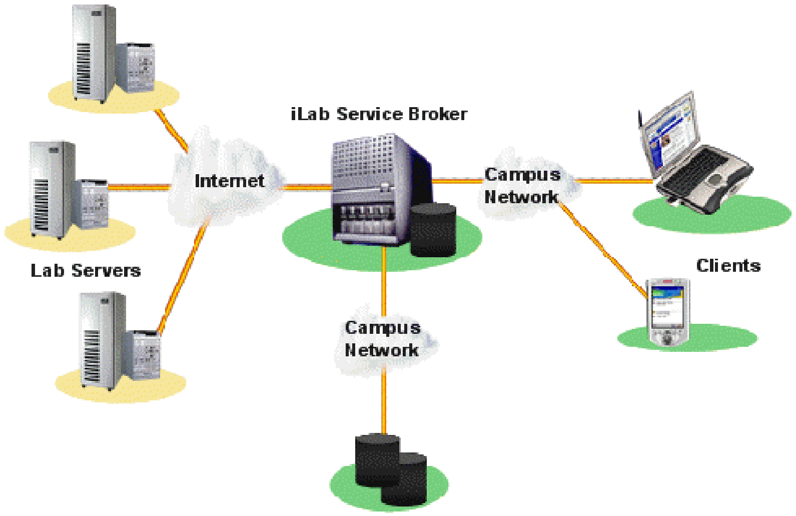


Figure 2.5: The iLabs architecture (Snowden, 2011)

Institutions can create their own Service Broker to share their own remote labs. iLabs also provides a public Service Broker that laboratory developers and users can make use of (Sancristobal et al., 2008; Piotr F Mitros, 2008). The Lab Clients and Lab Servers contain functionality that is specific to the laboratory, while the Service Broker is responsible for generic functionality (Yeung et al., 2010). This architecture is illustrated in Figure 2.5.

There are three API's that define the communication between the components: the Lab Client to Service Broker external web service API (specifies the communication between the users' client and the Service Broker); the external Service Broker to Lab Server web service API (specifies the communication between the Service Broker and the Lab Server); and the internal Service Broker Data Storage API (describes methods used to access and modify records in the Service Broker) (Sancristobal et al., 2008). The Lab Client to Service Broker API is described in Appendix C.

iLabs supports three categories of experiments: batched experiments (which run asynchronously, the user specifies the parameters and does not have to control the experiment while it executes); interactive experiments (where the user must be online to control the laboratory while it runs) and sensor experiments (which monitor or analyse real time data and need no user control).

While the iLabs Shared Architecture developed by MIT uses Microsoft software and can run only on Windows, the University of Queensland (UQ) has done work developing a Java implementation for batched iLabs experiments (Payne & Schulz, 2013). The UQ implementation further separates their Java Lab Server into a Lab Server (which handles the validation and submission of an experiment specification from the UQ Lab Client) and the Lab Equipment (which runs the experiment on the hardware).

The messaging between the UQ Lab Server and the UQ Lab Client are passed through a Service Broker. The Lab Server receives Simple Object Access Protocol (SOAP) calls from the Service Broker, and uses an *Identifier* (the Lab Server's GUID) and *PassKey* to authenticate requests from the Service Broker. This ensures that only authorised Service Brokers may send requests to the laboratory equipment. The Lab Client is launched by users logging into a Service Broker and selecting the experiment they want to run. The Service Broker generates a *CouponId* and *CouponPasskey* which are used in the SOAP calls to the Service Broker for authentication of all the Lab Client requests. (Payne & Schulz, 2013).

There is documentation and support available from the developers at UQ for new iLabs installations and use of their iLabs Service Broker and experiments. They also provide the functionality in the form of a 'dummy' Service Broker which transparently passes messages and can be used in development and stand-alone installations.

There are a range of laboratories worldwide that make use of the iLabs shared architecture such as MIT's force on a dipole experiment and the UQ's radiation experiment (*iLabs Around the World*, 'Physics Experiment'). In addition, iLabs based laboratories have been used in the literature for research into laboratory learning outcomes (Scheucher et al., 2009; Jona et al., 2011; Fischer, Mitchell, & Del Alamo, 2007).

2.2 Models

> *... mental models play a central and unifying role in representing objects, states of affairs, sequences of events, the way the world is, and the social and psychological actions of daily life. They enable individuals to make inferences and predictions, to understand phenomena, to decide what action to take and to control its execution, and above all to experience events by proxy...*
> *(Johnson-Laird as quoted in Matthews, 2007, p. 649.)*

Models can be defined as a *description of a phenomenon (object, process, event or system) that facilitates access to that phenomenon* (Bailer-Jones, 2002; Gilbert, Boulter, & Elmer, 2000).

Models are ubiquitous in science teaching across its many fields, throughout its history and in its current practice (Matthews, 2007). Historically, the natural science disciplines have built on and referred to explanations of empirical phenomena in order to acquire new knowledge, or correct and integrate previous knowledge. In order to do this, scientists build (and rely on) internal or externalised representations of reality (Coll, France, & Taylor, 2005; Gilbert, 2008; Matthews, 2007; Penner, 2000). These representations are the key element used to develop an understanding of the laws, theories or hypotheses that describe reality. Each of these representations can be considered a model and, consequently, models are key elements of modern science and engineering learning and practice.

This section looks at the literature on models, reviewing how models are used in scientific learning and identifying the different types of models that may exist. Of interest in this research (and investigated here) is the strengths and limitations of models. The relationship between models and laboratories as described in the literature is also explored.

2.2.1 The Role of Models in Science Learning

The use of models, analogies or metaphors in learning was recognised as early as Aristotle and Plato and differences in approaches to model use have been apparent since (Bailer-Jones, 2002; Matthews, 2007). Differences concern the 'truth' of models and how they relate to the real world they represent: Rationalists or Realists believe that models are real and therefore can be used to confirm theories; empiricists, positivists, constructivists (etc.) regard models as useful but unable to reveal nature and contribute to knowledge (some because they believe knowledge only comes from sensory experience, or that the human mind cannot grasp 'things as they are', etc.) (Matthews, 2007). There is support for the use of models from both those who seem to support the Realist view (Matthews, 2007) and those who support a constructivist approach (Duit, 1991; Penner, 2000). Gilbert et al. (2000) discuss the value of models from both perspectives. In looking at these links between models, theories and reality (as viewed from the philosophical viewpoints of Kuhn, Nersessian and Bunge) they conclude that 'a model is a readily perceptible entity by means of which the *abstractions of a theory* may be bought to bear on some aspect of the *world-as-experienced* in an attempt to understand it' (emphasis added) (Gilbert, Pietrocola, Zylbersztjan, & Franco, 2000, p. 34).

The literature on model-related research from epistemological and pedagogic approaches shows a growing awareness of the importance and use of models in teaching and understanding science (Coll et al., 2005; Duit & Treagust, 2003; Gilbert et al., 2000; Matthews, 2007). Coll et al. (2005) discuss how models are used in scientific *practice*, and suggest that this provides the justification for their use in science *education*. Crouch and Haines (2004, pp. 197-198) describe models and modelling as ‘particularly important in engineering, science and technology where transitions between real-world problems and the model are the substance of the discipline’.

Gilbert (2004) emphasises the role that models play in creating a bridge between scientific theory and the real world. The idea of models acting as bridge is repeated by a number of researchers. Models can act as a bridge between the real world and theory, between what is known by students and what is yet unknown, between novices and experts, between science education and design and technology education (Grosslight, Unger, Jay, & Smith, 1991; Gilbert et al., 2000; Giere, 2004; Crouch & Haines, 2004; Matthews, 2007; Coll et al., 2005; Liu, 2006).

The bridging role of models is emphasised by descriptions provided in the literature of how models relate to the real world. In Matthews (2007) this is described by means of different levels which exist between Gilbert, Pietrocola, Zylbersztjan, and Franco’s (2000) ‘world-as-experienced’ and ‘abstracted theory’. These levels are:

- level 1: the scientific laws or theory which are fundamental and high-level;
- level 2: phenomena which can be represented by models;
- level 3: observations and measurements of events occurring in the world;
- level 4: the real objects, events and processes that exist in nature.

This is supported by Bailer-Jones (2003) in distinguishing between *theories*, which are about abstract objects, and *models*, which are applied to concrete phenomena. Giere (2004) used similar categories to describe how scientists generate *models* which are based on *principles plus specific conditions* to represent aspects of the real world.

Duit (1991) in discussing analogies (with the explicit understanding that ‘model’ and ‘analogy’ are often used interchangeably), identifies the role that they play in conceptual change learning. Models can:

- open up new perspectives to students;
- facilitate the understanding of abstract concepts by pointing to similarities in the familiar real world;
- allow student to visualise the abstract;
- aid in motivation by provoking students’ interest;
- encourage teachers to consider students’ prior knowledge, including revealing their misconceptions (an advantage from a constructivist point of view).

Frigg and Hartmann (2013) justify the use of models as a tool for ‘surrogative reasoning’: the investigation of models (rather than the real world itself) allows discovery of facts and features of the system the model represents. The process whereby students learn through models is described (after Hughes) as: *denotation* (establishing a representational relation between the model and the target); *demonstration* (learning about the model by investigating its features); and *interpretation* (converting findings from the model into claims about the target system). (This concept of the model acting as a proxy for a real world situation will be revisited in section 2.2.5.)

Bailer-Jones (2003) identifies a number of functions of models and models-within-models in learning: explanation; technical application; guiding experimentation; promoting creative insight and imagination. Gilbert et al. (2000) described their functions as: making abstract entities visible; providing descriptions and/or simplifications of complex phenomena; and providing the basis for both scientific explanations of and predictions about phenomena.

This discussion of the roles that models play in learning and the function they fulfil illustrates the wide acknowledgment that understanding and using models is essential in the sciences. However, the literature also identifies that students may have difficulties using models. The literature distinguishes between how *students* use models as opposed to how *experts* use models:

- experts use models pragmatically to explain and describe concepts, while understanding that models are limited in depicting reality (Coll et al., 2005);
- students may have trouble using models effectively because of a lack of understanding of their nature as partial representations of reality (Grosslight et al., 1991; Duit & Treagust, 2003; Wofford, 2008).

Some of the factors that typically limit students' learning from models have been identified by Coll et al. (2005):

- students may learn the model rather than the concept the model represents;
- they may not be aware of the boundary between the model and reality;
- they may lack the ability to visualise the reality;
- they may have difficulty applying the model to a different context.

Duit (1991) (considering analogies) also highlights features of analogies and models that may mislead students:

- they are never based on an exact fit, and different features between the model and real world (or analog and target) may mislead;
- students misconceptions in one domain will transfer them into the other domain. Students need to understand the nature of analogy for effective model use. This requirement of understanding of the analogy is supported by Gilbert (2004).

- analogical reasoning must be guided to ensure that students can make inferences from this.

The limitations that students face all have in common the understanding of the relationship between the model and reality. The implication of this is that developing students' understanding of a model's relationship to reality can help shift their use of models from the novices they begin as, towards an expert understanding of all models.

It can be seen from this discussion that, while models are accepted and ubiquitous in science education, there is scope to improve how students use and learn from them. Some suggested strategies reported in the literature are the use of 'authentic contexts' (Prins, Bulte, Van Driel, & Pilot, 2008), visualisation (Gilbert, 2008), animations (Lowe, 2004) or simulations (Holton, 2010).

2.2.2 Types of Models

If models are *description of a phenomenon that facilitates access to that phenomenon*, then anything used in science to describe empirical phenomena using any form, is a model. The literature shows a large number of characteristics that can be used to classify the different types of models.

Gilbert (2004) classifies them in a number of ways, first in terms of their progressive development:

- *mental models* are cognitive constructions used to describe phenomena that cannot be experienced directly;
- *expressed models* are mental models which have been 'expressed in the public domain through action, speech, writing or other symbolic form';
- *consensus models* are expressed models which have gained general acceptance in society;
- *scientific models* are consensus models currently being used in science;

He also adds *historical models* (consensus model that were previously used but now have been superseded), *curricular models* (simplified scientific or historical models used to help in learning), *teaching models* (which support the teaching of curriculum models) and *hybrid models* (types of curriculum models that merge a number of historical models). Gilbert (2004) also classifies models in terms of the mode of representation of the model:

- the *concrete mode* is a three-dimensional, material model;
- the *verbal mode* is a written or spoken description of the entities and the relationships

between the entities, or the metaphors and analogies on which the model is based;

- the *symbolic mode* is the use of symbols and formula, such as mathematical expressions and particularly equations;
- the *visual mode* is the use of graphs, diagrams, and animations;
- the *gestural mode* makes use of the body or its parts.

These modes are not exclusive and combinations do exist.

Gilbert (2008) provides another classification of models based on their representational 'levels':

- the macroscopic level is what is seen in what is under study - 'a chunk of the world-as-experienced that science is able to explore conveniently' - for example a chemical solution;
- the sub-microscopic level is representations of those entities that make up the macroscopic level, for example the ions in a chemical solution;
- the symbolic level is the 'qualitative abstraction' that describes the sub-microscopic level, for example the chemical equations that describe a chemical solution;

Gilbert (2008) further describes that each of these levels can be represented in either three-dimensional (or pseudo three-dimensional such as in a virtual world), two-dimensional or one-dimensional formats.

Frigg and Hartmann (2013) also illustrate a variety of ways that models may be classified. From a semantic viewpoint, models can be *models of theory* which interpret a theory or the axioms of the theory, or *representational models*, which represent a selected part of physical reality. Representational models can either represent a phenomenon of the real world or they can be *models of data* which are corrected, rectified or even idealised versions of the raw data. Further, representational models may be:

- *material models* are physical objects that serve as representation, such as models of bridges or planes;
- *non-material models* are representation by formal languages, natural language descriptions as well as the application of artificial languages and symbols, such as calculus.
- *scale models* are smaller or enlarged versions of the target system;
- *analogical models* build on relevant similarities of properties or relations between parts of the representation and the target system;
- *phenomenological models* focus only on observable properties of interest and shade hidden mechanism;

- *idealised models* simplify complexity by neglecting some mechanism (termed an *Aristotelian idealisation*) or deliberately distorting a characteristic (or a *Galilean idealisation*);

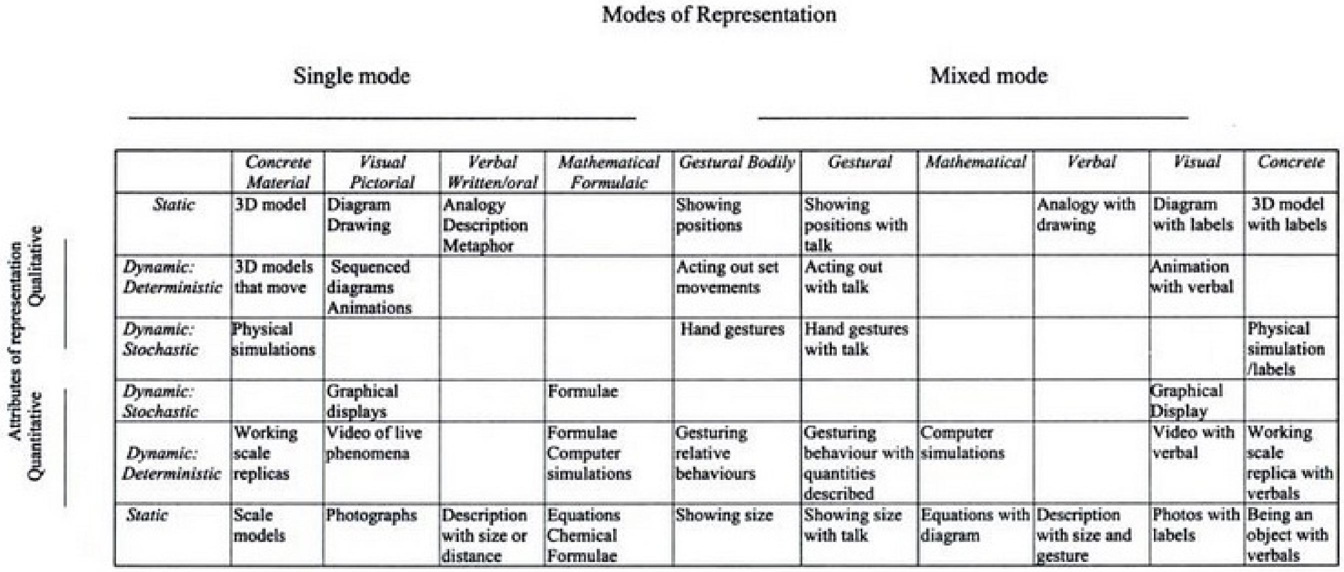
Penner (2000) identifies models as *physical* (material) or *conceptual* (which exist in the minds of humans), as *expedient* (exhibiting behaviour similar to the target) or *explanatory* (which gives insight into how a phenomenon arises) and describes *synthetic models* (using artificial components such as a computer to model a real world phenomenon from the bottom up).

Boulter and Buckley (2000) acknowledge the large ways that exist to classify models, and suggest a typology that can be used to describe them in terms of the mode of representation (as described above for Gilbert (2004)) which can be *single mode* or a *mixed mode*, and considers the models' 'attributes'. Attributes are either *qualitative or quantitative* (for example, precise scale drawing or equation); *static or dynamic* with respect to their behaviour over time; and, for dynamic systems, whether the representation is *deterministic or stochastic*. They provide an excellent summary of the typology for typical models found in science education with a table indicating how they can be classified according to mode of representation and their attributes. This is reproduced in Figure 2.6.

Over our human evolution, auxiliary tools, devices and increasingly sophisticated technology have significantly improved ways to experience our world and explain phenomena in the continuum from a micro to a macro level. As such, modelling has become more pervasive, varied and abstract and describing the types of models that exist relies heavily on the aims of the classification. What is consistent across the definitions, identified functions and classifications of types of models presented here is their representative nature. There has been much written about how closely models 'mirror' reality and whether they contain truths and falsities. Matthews (2007) identifies the work of psychologists and cognitive scientists as being very influential in model related research, however a distinction is made between the approach of psychologists, who identify the usefulness and necessity of models in reasoning and learning about the world, and educational approaches, which require a valuation of the 'truth' of models. Or in other words, *how* learning occurs is independent of whether or not *what* is being learnt is correct, however for educational purposes it is important to understand whether models are 'correct'.

2.2.3 The Truth of Models

> *.. all models are wrong ..*
> *(Box, 1976, p. 792)*



Modes of Representation

Attributes of representation		Single mode				Mixed mode					
		Concrete Material	*Visual Pictorial*	*Verbal Written/oral*	*Mathematical Formulaic*	*Gestural Bodily*	*Gestural*	*Mathematical*	*Verbal*	*Visual*	*Concrete*
Qualitative	*Static*	3D model	Diagram Drawing	Analogy Description Metaphor		Showing positions	Showing positions with talk		Analogy with drawing	Diagram with labels	3D model with labels
	Dynamic: Deterministic	3D models that move	Sequenced diagrams Animations			Acting out set movements	Acting out with talk			Animation with verbal	
	Dynamic: Stochastic	Physical simulations				Hand gestures	Hand gestures with talk				Physical simulation /labels
Quantitative	*Dynamic: Stochastic*		Graphical displays		Formulae					Graphical Display	
	Dynamic: Deterministic	Working scale replicas	Video of live phenomena		Formulae Computer simulations	Gesturing relative behaviours	Gesturing behaviour with quantities described	Computer simulations		Video with verbal	Working scale replica with verbals
	Static	Scale models	Photographs	Description with size or distance	Equations Chemical Formulae	Showing size	Showing size with talk	Equations with diagram	Description with size and gesture	Photos with labels	Being an object with verbals

Figure 2.6: Typology for models (Boulter & Buckley, 2000, p. 49)

Box's (1976) statement that all models are wrong does not invalidate them, rather, he suggests that an 'economic' description of natural phenomena with no excessive elaboration is a sign of good science. It is agreed through the literature that models will vary with purpose and their representation must be analysed in terms of the aims for the model rather than their realism. Frigg and Hartmann (2013) describe two of the problems with using models as representations: to 'explain in virtue of what a model is a representation of something else' and what style of representation is most appropriate for a given purpose given the many different models that can be used. As an example Matthews (2007) describes how an apple will be modelled differently by an economist (exchange value), a dietitian (calories and carbohydrates), farmer (return on investment) etc.

Bailer-Jones (2003) specifically looked at whether models can be analysed in terms of their truth or falsity. She looked at the models as 'entailing propositions' meaning that some of a models' content can be expressed in terms of propositions which express their 'message'. Models may be 'neither true nor false'. Bailer-Jones (2003) identifies the sources of falsity in a models' propositions as approximations and construct or causal idealisation.

- *Approximations* refer to how well the model fits empirical data. Whether an inexact proposition due to approximation leads to an incorrect model depends on the deviation from reality that is deemed as acceptable by the model user.
- *Construct idealisation* occurs when the representation of the phenomenon (and not the phenomenon itself) is simplified. (This is the Galilean idealisation referred to by Frigg and Hartmann (2013).) This could include leaving out features of the phenomenon entirely or treating them as simpler mechanisms in order to create an analogue of the phenomenon that is simpler than the real phenomenon so that a selected aspect of it can be studied. The selection of which aspects of a phenomenon to model affects the propositions entailed in the model and may implicitly lead to the acceptance of false propositions. Construct idealisation does not necessarily lead to a false proposition (though it can). Determining falsity depends how well the simplified model works.
- *Causal idealisation* is when the problem situation itself is simplified, and the model created of the simplified system (Frigg and Hartmann's (2013) Aristotelian idealisation). This often happens within a laboratory equipment. The determination of truth or falsity in this case depends not on whether the propositions are true of the idealised phenomenon, but if they are also true of the original proposition. Once again this is a pragmatic decision made on the purpose the model aims to fulfil.

Another factor that may affect the truth or falsity of propositions entailed by a model is the availability of new data which can add more propositions to a model, ‘prove’ a proposition to be true or false, or affect how accurate it is.

None of these sources of error alone determine the falsity of propositions within a model, rather it is clear from this discussion that subjective decisions are involved in evaluating falsity in a model’s propositions and with regard to how heavily to weigh false propositions in assessing a model (often true propositions will be considered more important that false propositions). This requires input from the model user, specifically to identify the function of the model. Bailer-Jones (2003) suggests that those ‘propositions that are crucial for meeting the intended function of the model are not allowed to be false, while others less central to the function can be false without doing much damage’. She concludes that a propositional analysis of models is insufficient to describe their representational relationship to the real world: models may (and often do) include false propositions and in assessing models the model users’ views of the function of the model, its fit with the data and the aspects of the phenomenon that are modelled all form part of the representational analysis.

In discussing simulations (as a type of model) Frigg and Hartmann (2013) identify two areas where the ‘trustworthiness’ of a simulation can be called into question: validation (whether the equations of the model represent the target system accurately enough for the purpose of the model) and verification (whether the computer provides accurate enough solutions of these equations). Similarly to the broader discussion of models, this relates a simulations’ trustworthiness not to its accuracy alone, but to its purpose as well.

Bender (1978) defines a model as a ‘construct related to a part of reality and created for a particular purpose’ and states the ‘ultimate test of a model is how well it performs when applied to the problems it was designed to handle’. Models are always used for a particular purpose, and as a result will always have limited applicability and will be restricted to specific contexts. This highlights again the importance of understanding the purpose of the model, as well as the fact that it is intended to represent only a ‘part of reality’.

The literature has been shown to agree that the usefulness of a model is not determined by the measure of the reality, or accuracy of the model, but rather how well it links to the reality it is attempting to describe and whether it fulfils its function (Bailer-Jones, 2003; Coll et al., 2005; Frigg & Reiss, 2009; Giere, 2004). Understanding that all models will necessarily be limited in which aspects of reality are represented is essential when using models for learning and being able to apply learnt knowledge effectively.

2.2.4 The Strengths and Limitations of Models

> *It is inappropriate to be concerned about mice when there are tigers abroad.*
> *(Box, 1976, p. 792)*

What Box (1976) meant was that, while all models are wrong, scientists need to understand what is *importantly* wrong. There is an enormous amount of the real world that is not captured by any particular model or is portrayed incorrectly, but only some of this is relevant. Identifying which factors are 'importantly' wrong allows one to begin to analyse a model and its relationship to the real world.

Recurrent in much of the research is that students' should understand the nature of models in order to derive the learning benefits from them (Grosslight et al., 1991; Gilbert et al., 2000; Penner, 2000; Prins et al., 2008). Recognising a models' strengths and limitations is essential in developing this understanding. Grosslight et al. (1991) identify three progressive levels of understanding of the nature of models which identify an understanding of their strengths and limitations as representations of the real world:

- Level 1: models are thought of as either toys or simple copies of reality which are useful as they provide copies of actual objects or actions. This level shows limited understanding that some aspects of reality are missing from the model.
- Level 2: the realisation that the model is constructed for a specific purpose. It involves an understanding that conscious choices were made in the construction of the model and a realisation that it does not necessarily correspond exactly with the real-world object being modelled. The focus at this level is still on the model and the reality modelled, not the underlying ideas.
- Level 3: this level shows an understanding that the model is constructed to develop an understanding of ideas rather than to copy reality, that there have been choices made in its construction and that the model can be manipulated and changed.

Coll et al. (2005) endorses this, describing the effective use of models that are known to possess limitations as one of the characteristics that differentiates experts from novices. Gilbert (2004), in discussing the implications of a model-based curriculum for science, identifies students' failure to recognise the scope and limitations of different modes of representations in models as one weakness of using a wide range of models and modes of representation. These levels of understanding also reflect the shift from a 'novice' approach to an 'expert' approach that science teaching should aim to develop.

Given the importance of understanding the strengths and limitations of models, an analysis of a model should be done to determine what these strengths and limitations may be. A framework given by Gilbert (2008) facilitates this identification of the strengths and limitations of models by relating the model to its function. Gilbert maintains that ‘all models are produced by the use of analogy’ with the ‘target’ being the subject of the model and the model itself being the ‘source’ which provides a partial comparison. In the development of these analogies, the following variations can occur between the target and the source:

- the source can be the same as the target, only scaled smaller or larger;
- the source may be an abstraction based on the target, representing only a selection of the targets properties;
- the source may be an idealisation of the target with all its characteristics present, but emphasis placed on a selected properties;
- the source may represent average properties of a target, rather than specifics (representing a class of phenomena rather than individual case);
- the source may be different from the target but include a process that is the same or analogous between source and target. (Gilbert, 2008)

Identifying which variant a model includes would provide an indication of where the model may succeed or fail as a predictor of the real-world behaviour.

Bailer-Jones’s (2003) analysis of models (discussed in 2.2.3) provides a framework that can explicitly account for how a model represents reality by looking at the possible false propositions entailed in them through idealisation and approximation, as well as taking into account the model users’ views on function. This is supported by Corter et al. (2011) who state that ‘the power of theories stems from their ability to predict actions and behaviours in the real world, and their limitations stem from the simplifications involved in these predictions’. Bailer-Jones’s (2003) analysis allows a model to be interrogated in detail to determine where it succeeds and fails as a predictor of real-world behaviour.

From the literature it is apparent that understanding the relationship between the real world and the model is critical but often problematic in science and engineering education. To better facilitate this understanding, laboratories are often used as a tool for supporting learning. It is therefore useful to consider the relationship between laboratory experimentation and models.

2.2.5 Models and Laboratories

> *Models are experiments, experiments are models.*
> *(Mäki, 2005, p. 303)*

Laboratories are models: they meet the definition of providing a (physical) description of a phenomenon that facilitates access to that phenomenon. According to just some of the classifications described here, laboratories can be considered to be expressed, material, macroscopic, representational models. The roles that models and laboratories play in learning that have been identified in literature overlap significantly, for example they both facilitate understanding of abstract concepts by pointing to similarities in the familiar real world and aid in visualising the abstract. Mäki (2005) justifies the phrase 'models are experiments, experiments are models' in terms of the common representational function of the two.

The understanding of models is one of the learning objectives of laboratories identified by ABET (as discussed in section 2.1.3). Specifically students should be able to '[i]dentify the strengths and limitations of theoretical models as predictors of real-world behaviors' (Feisel & Rosa, 2005). This learning objective describes how *laboratories*, which are models, are used to understand other *theoretical models*. This concept is supported in the literature, where one 'mode' of model (in this case the material laboratory) is used to investigate another (in this case, the underlying theoretical model) as described by Gilbert (2004) and Mäki (2005).

To make sense of the discussion, a distinction will be made for this research: the *model* is the underlying theoretical or conceptual (partial) representation of reality that is the focus of analysis within the laboratory activity and the *laboratory* is a system that is used to investigate the underlying theory. The laboratory is a proxy for reality that allows establishment of the relationship between the theoretical model and reality.

The laboratory's function as a proxy for reality is supported by Frigg and Hartmann's (2013) notion of 'surrogative reasoning' and by Matthews (2007) who quotes Philip Johnson-Laird's book *Mental Models* (1983) as stating that models enable individuals to 'experience events by proxy'. Mäki (2005) supports this idea too, describing 'substitute systems' where, by focusing on the properties and behaviour of a representative system (rather than the target system), information on the target system is indirectly acquired.

By definition, both the laboratory and the underlying theoretical model are partial representations of the real world. As per the discussion above, the theoretical model will have been chosen for the model users' purpose to fulfil a function and will entail both true and false propositions which affect how the model performs as a predictor of real-world behaviour. The laboratory is a proxy for the real world, and it too (by virtue of it being a model) will be affected by selectivity, approximations and idealisations. The relationship, therefore, between the real world, the laboratory and the underlying model is not straightforward or symmetrical and depends heavily on the purpose of the laboratory and the model. This three way relationship is illustrated in Figure

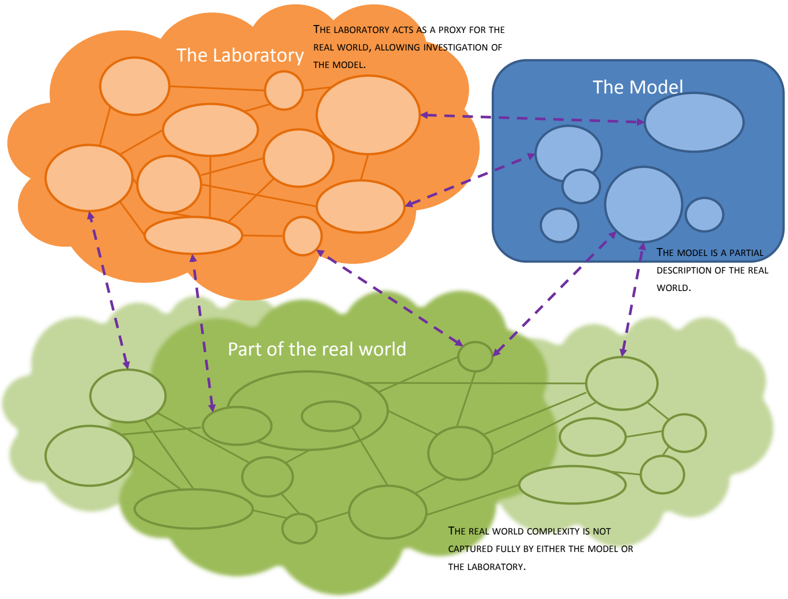


Figure 2.7: The relationship between laboratory, model and the real world

2.7.

In conducting the laboratory activity, students are developing an understanding of the relationship between the theoretical model and the experiment. Given the mapping from experiment to reality, we are therefore aiming to support the development of an understanding of the relationship between the theoretical model and reality.

There are aspects of the model which are represented within the laboratory, but there are also (by the nature of models) aspects that exists in the lab equipment which are not described by the model. Similarly, the model will contain information (often assumptions, or idealised conditions) that are not clear from the lab equipment being used to investigate it. This asymmetric relationship also exists between the model and the real world, as well as between the laboratory and the real world. For example, in most cases the laboratory will represent only one out of many possible applications of the model.

The nature of the laboratory as a proxy for reality implies that shortcomings in fully understanding the model will, very generally, fall into one of two categories:

1. An incorrect or incomplete understanding of the relationship between the model and the laboratory. For instance, the laboratory may contain elements of reality that are not present in the model and students do not fully comprehend this.
2. An incorrect or incomplete understanding of the relationship between the laboratory and

> reality. For instance, the laboratory is usually just one (often very simplified) example of the application of the model, but students need to understand that it is not limited to this use.

Despite the apparent role of laboratory experimentation in developing a strong understanding of models (and especially their strengths and weakness with regard to reliably representing reality) there has been only limited consideration within the literature of the relationship between laboratory experimentation and either model representation or model evaluation (Gilbert, 2004; Mäki, 2005; Liu, 2006). Amongst those papers that identify the laboratory learning outcome concerning the understanding of models, many do not draw conclusions concerning the extent to which this learning objective was met (Mason, Shih, & Dragovich, 2007; Hashemi et al., 2006; Hendeby, Gustafsson, & Wahlström, 2014). Some do report improved results for the model learning outcome stemming from the introduction of new laboratory activities, such as the introduction of web based remote labs which promotes inquiry learning (Fischer et al., 2007), or support for model-based teaching (with a computer modelling activity) to enhance learning outcomes for traditional laboratories (Liu, 2006).

Looking specifically at remote laboratories and how these may be used to achieve the better understanding of models, there is no empirical study reported on this topic. However, there is support for the fact that this learning objective, falling as it does into the categories of 'conceptual understanding' (as opposed to professional design or social skills) can be achieved to at least the same degree in a remote lab as in a hands-on lab with a suitable laboratory design (Ma & Nickerson, 2006; Fischer et al., 2007; Hashemi et al., 2006). In support of this, Jona and Adsit (2008, p. 6) suggest online labs combined with simulations 'can highlight the distinctions between models of physical processes or phenomena and their actual behavior captured and examined remotely'.

The review of the literature on models has shown that they are widely accepted as an essential tool in the process of learning and that the understanding of models is a requirement for science education. Laboratory activities are one of the ways that students can acquire a better understanding of models, in fact this is an identified learning objective of labs. However, the link between laboratory activities and the understanding of models is an area of research that has scope for more investigation.

2.3 Context

Context can be broadly defined as the *interrelated conditions in which something exists or occurs* (Merriam-Webster, 2015). Hofstein and Lunetta (2004) have described the current (largely constructivist based) perception that 'learning is contextualised and that learners construct knowledge by solving genuine and meaningful problems'. Of particular interest in this research is the effect that context may have on laboratory learning outcomes.

It is widely acknowledged that in any learning environment, the circumstances in which the learning occurs, or its context, is important to the learning outcomes (Balsam & Tomie, 2014; Tessmer & Richey, 1997; Trigwell & Prosser, 1991). This section of the literature review focuses on the role that context plays in science learning. It begins with clarifying the nature of the context that will be used in this research (domain context). The developments and the different approaches that have been taken to the role of context in the learning process are reviewed, giving specific consideration to the relationship between context and content, and to the role of context in science learning. Finally, the literature on context use in laboratories and the effect on lab learning outcomes is explored.

2.3.1 Definitions of Context

The definitions of context are wide ranging and often very broad in the literature. The circumstances before and during learning, assessment and recall can be considered to be part of context. This can include the personal attitudes and histories of learners and teachers, the physical and technological environment, even the broader society and culture in which learning takes place (Klassen, 2006; Finkelstein, 2005). This research, after analysing the differing definitions and approaches to context, considers contextual elements as those elements that are not the direct subject of consideration, but are nevertheless discernible by a learner and which play a role in influencing the interpretation of a concept or artifact under study and thereby play a role in influencing learning.

Much of the literature reviewed in this research concerns the aspects of context that are independent of the content under study, while a portion of it deals specifically with how the context and content of the learning are related. For a laboratory activity, as with all other learning, the context within which it is completed can be considered to be comprised of contextual elements that relate directly to the content under study and those that are independent of the specific learning task but may still affect the learning outcomes. The relationship between context and content is not straightforward. Finkelstein (2005) states that 'the boundaries of context and content are dynamic, shifting with goals, participants, and setting'. It is, however, useful for the following discussion to distinguish between these two general categories of context. This research has therefore contributed the following definitions to differentiate between the content dependent and independent contextual elements in a laboratory environment:

- *Situational context* is the environment (physical, personal, social, technological, etc.) in which the laboratory is being conducted. The situational factors are independent of the specific laboratory being conducted.
- *Domain context* refers to those elements of context which are specific to the content under study. These elements relate to the specific laboratory equipment, the underlying model being investigated, the learning outcomes being targeted and the method of executing and assessing the lab activity.

Examples of domain context may be a student's prior knowledge of the subject, the laboratory equipment itself, or additional examples in lab guides and supporting documentation. Situational context includes, for example, the student's age, the number of students in a lab class and the technical environment. These definitions of context will be used in this research to relate the literature reviewed to the concepts relevant for this research.

2.3.2 The Role of Context in Learning

> *... it is not appropriate to discuss student learning absent from the context with which it is intertwined.*
> *(Finkelstein, 2005, p. 1206)*

Context and related concepts have been studied within the educational literature for a considerable period. As an early example of the research, Ausubel's (1960) theory of *advance organisers*, whilst not explicitly referring to context, does provide a mechanism for exploring context, albeit a context that has a direct subsuming relationship to the concepts being explored. Of particular interest is the notion of *comparative organisers*, which are used to activate existing knowledge schema and hence 'to increase discriminability between the new ideas and the previously learned ideas by pointing out explicitly the principal similarities and differences between them' (Ausubel, 1978, p. 273). We can conceive of an explicitly provided domain context as a form of advanced organiser, and where the concept is familiar (as in a laboratory that follows a classroom discussion) that context may constitute a comparative organiser.

Novak takes the idea of comparative organisers further, introducing the concept of a *cognitive bridge* and emphasising the linking function of Ausubel's advanced organisers: 'cognitive bridges are short segments of learning material that provide guidance to the student as to which concepts in his cognitive structure might best be employed to learn meaningfully. They also help to signal what will be the key concept(s) in the new material and how these may bear a subordinate or superordinate relationship to concepts the learner already possesses' (Novak, 1976, p. 500).

Kokinov's (1999) classification of context also has parallels with Novak's cognitive bridge. Kokinov approaches context from the point of view of how the state of the environment is perceived and then internal representations of this are constructed by the learner. He discusses the role of three different processes involved in the mental construction of context and which are in turn affected by the context:

- *perception-induced* context is that contextual information available through the current perception of the environment;
- *memory-induced* context is information obtainable from memory and previous context representations that are recalled;
- *reasoning-induced* context is information derived through reasoning.

Kokinov goes on to provide a useful definition of context as 'the dynamic fuzzy set of all associatively relevant memory elements (mental representations or operations) at a particular instant of time' (Kokinov, 1999, p. 206). Students make use of these context representations during the learning process and therefore a learning environment which has an effect on these processes will alter the context and hence, potentially, the learning outcomes (Kokinov, 1999; Demetriadis, Papadopoulos, Stamelos, & Fischer, 2008).

Yang (2003) presents a framework for bridging different approaches to knowledge that describes three facets of learning: explicit; implicit and emancipatory. Within science learning, explicit knowledge can be considered theoretical knowledge or a model, and implicit knowledge can be considered the practical or applied component of knowledge. Emancipatory knowledge in science learning relates to the social and motivational aspects of learning. Yang discusses the dynamic relationship that exists between these facets of knowledge. 'Contextualisation', as part of this relationship, is the process that transforms explicit knowledge into implicit knowledge by utilising (amongst other things) models in a specific context. Yang describes contextualisation as a learning process that 'makes sense of previous experience'. This process of contextualising knowledge echoes aspects of Novak's idea that domain context can provide a cognitive bridge that aids in meaningful learning, as well as Kokinov's process of creating internal representations of context that are used for learning.

Gilbert (2006) describes the role that context plays in 'making meaning' within the learning theories of constructivism, situated learning, and activity theory, each of which can account for how the context can aid in learning as described by the theory.

Ausubel, Novak, Kokinov, Yang and Gilbert provide insight into the link between context and the learning process that occurs when students complete contextualised learning activities. Their research supports the proposition that domain context will have an effect on this learning processes.

2.3.2.1 Context and Content

While much of the research into how context affects learning cited here relates to situational context, there is acknowledgment that adding information that more closely links the activity with the real world - domain context - will affect learning outcomes. Of interest in this research is not only how context may facilitate learning, but what elements make up domain context. For this, literature that relates context to the content under study has been investigated.

Klassen's (2006) approach looks at which broad categories of contextual elements are relevant within specific activities. Klassen describes context in learning as including practical, theoretical, social, historical and affective context. Based on these categorisations, and how each factor can be influenced, Klassen developed the Story-Driven Contextual Approach (SDCA). He argued that learning can be contextualised by providing a 'story'. Delivered by a narrative, the story provides focus and motivation. Students then engage in self formulated or teacher supplied investigations involving a number of activities, all of which take place within the five types of contexts being supplied by the story and the students' own knowledge, ideas and experience. Klassen's work provides insight into the different elements that construct the total context and how they can be categorised, as well as broadly arguing for a specific approach (contextualisation through narrative). Klassen suggests that the context forms a narrative to support learning.

Van Oers (1998) takes a different approach. Rather than considering context as any element that affects the interpretation of concepts, van Oers looks at how content (or meaning) and context are related, describing two functions of context in learning: to support the 'particularization of meanings' and to 'provide for coherence'. Context *particularises meaning* by supplying additional information that focuses the learning on the appropriate interpretation of the concept being learnt and aims to eliminate ambiguities or possible misinterpretations not appropriate to the specific meaning. Context can *provide coherence* by relating content to a 'larger whole' so that the knowledge is not restricted to a particular meaning or situation.

Van Oers (1998) distinguishes three different approaches that can be taken towards how context is related to the meaning being sought, each of which aims to achieve the main functions of coherence and particularisation:

1. *Embeddedness in cognitive structure*: using the pre-existing cognitive structure as an anchoring point for embedding new material so that it can provide particular meaning and coherence.
2. *Situation-as-context*: a meaningful experienced situation - one that makes 'human sense' - provides particularisation and coherence.
3. *Activity-as-context*: context is 'embeddedness in activities'.

Barab et al. (2007), similarly to van Oers (1998), focus on the relationship between scientific 'formalisms' and the situations of use which provide a context for those formalisms. Formalisms are the focus of the learning, the underlying theoretical components which students are required to learn. Consideration is given to the nature of the relationship between the formalism and the 'context of use'. A formalism may be directly experienced by the learner within a specific instance such that the meaning is inherently bound up with the specific instance. In this case the formalism is considered to be *embodied* by the context of use. Conversely, if the formalism is drawn out of, and understood as a separate concept from the specific instance in which it might be explored, then it is considered to be *embedded*. Embedding and embodying the formalism can be said to achieve van Oers' function of 'particularizing meaning'. Once the formalism is further related to other contexts of use, beyond the one in which might have been originally learnt, then it is considered to be *abstracted*. The context that provides an abstracted formalism provides van Oers' 'coherence' by placing the content being learnt within a larger representation of reality. Barab et al. further describe that the specific relationship between the formalism and the context of use can be either explicit or implicit.

Barab et al.'s (2007) research commences with the objective of 'establish[ing] a rich context through which scientific formalisms are embodied, embedded, and eventually abstracted' but their focus shifts to exploring the extent to which narratives can fulfil this purpose. Their work provides some interesting insights into the design of contexts - represented as design principles for a context that was shown to be pedagogically useful:

- establishing embodiment that provides a clear and legitimate role to students that gives value and meaning to their actions;

- illuminating context-context relations;
- fostering of an analytical stance through encouraging a sense of participation;
- development of multiple representations of formalisms, potentially through derivative contexts. (Barab et al., 2007).

In their work, Barab et al. (2007) acknowledge that there is a balance that needs to be achieved when designing contextual elements for a curriculum between the ’quality of the context’ and the ‘quality of the formalism’. The context can be detailed at the risk of being distracting (or noisy) and the formalism can range from explicit (and potentially quite formal) to implicit (and potentially inefficient).

The case for accurately contextualising activities to facilitate learning has been made for problem solving in case studies, for field studies, for better understanding models, sound decision making, and more generally, for acquiring knowledge that can meaningfully be used (Overton, 2001; Crouch & Haines, 2004; Brown, Collins, Duguid, & Seely, 1989; Goel, Johnson, Junglas, & Ives, 2010). This has been discussed in the literature across multiple educational disciplines ranging from languages, through economics, engineering and adult education, to mathematics (Chambel, Zahn, & Finke, 2004; Levitt & List, 2007; Lindsay et al., 2007). It is useful to look specifically at the use of context in a science learning environment.

2.3.2.2 Context in Science Learning

In a broad review of context-based and science-technology-society approaches to science teaching, Bennett, Lubben, and Hogarth (2007) conclude that these approaches result in improved attitudes to science and they support the use of contexts as a starting point in science teaching.

Finkelstein (2005) specifically considers context for physics education, developing a model for context that uses three ‘frames’ of context: ‘Tasks are embedded in situations that are located in idiocultures’ Finkelstein (2005, p. 1192).

- *Tasks* are the context or storyline of a problem and involve actions, a content and the learner;
- *Situations* are the context of the task, such as where, how and why the task is being done;
- *Idioculture* is the context of the situation, or the specific customs and behaviours describing the environment in which situations occur.

Finkelstein (2005) concludes that context is intrinsic to physics learning and that context changes (and is changed by) students and the learning content. Different features of context will support or hinder the learning of different concepts for individuals.

In a very relevant paper concerning context and science education, Gilbert (2006) explores the use of context in developing curricula for chemistry education. He describes context as it is practically understood as 'the circumstances that form the setting for an event, statement, or idea, and the terms in which it can be fully understood'. Accordingly, context must 'provide a coherent structural meaning for something new that is set within a broader perspective'. He summarises four attributes of context (based on Durranti & Goodwin) and adapts these to chemical education:

- *Attribute A: Setting.* The 'social, spatial, and temporal framework' of the context. This is a setting students should recognise and value.
- *Attribute B: Behavioural environment.* The way the encounters and tasks involved frame the content under study (the *talk*, for Duranti and Goodwin).
- *Attribute C: Specific language.* The language used shows the emphasis placed on the content (it is closely related to the setting and behavioural environment).
- *Attribute D: Relationship to 'extra-situational background knowledge'.* Links between the context and students' knowledge and experience.

Gilbert (2006) believes that major challenges faced in chemistry education could be addressed with the use of a collection of contexts within a curriculum, providing they are suitably designed. Gilbert identifies five problems: curricula overloaded with content; students being taught isolated facts and not how to connect these; students' limited ability to transfer knowledge to problems different from the way in which they were taught; students' belief that chemistry is 'irrelevant'; and a focus on providing a solid base of chemistry knowledge rather than developing scientific literacy. He identifies how context can address these problems:

1. Context can be used to simplify or reduce the content of a curriculum by focusing on the most important and recurring concepts in a potentially overloaded curriculum.
2. Context can support students' development of mental models of the relationship between the facts presented (a constructivist approach).
3. Context may make the transfer of knowledge 'more likely'.
4. Context should engage all students (with some of these becoming very interested).
5. A collection of contexts for a curriculum must be sufficiently flexible to be tailored for different students, and an expanded focus of education beyond providing a solid foundation.

The first four of these suggestions for context design can be mapped from a curriculum level to the context for a single activity. While these potential benefits of context are argued in the case of chemistry curricula, the challenges are common to many fields of science education where the similar acceleration in scientific knowledge has an effect on the curricula. Gilbert (2006, p. 959) states that 'all adult learning of all the sciences takes place in these conditions'.

Of particular interest for this research, as it combines the concepts of context provided by organisers and the use of models for learning, is Gilbert's (1989) investigation into using analogies in science texts as organisers. He concludes from his study that there are no positive results for student performance. One suggestion for this problem is that providing an analogy in written text format (in one case, describing the flipping of coins rather than letting students do a coin-flipping exercise) requires extra reading and assimilation. This should be used as a caution in the provision of context for activities, and relates to Barab et al.'s (2007) and Chambel, Zahn, and Finke's (2004) warning on the potential for additional domain context (though not referred to as such) to be distracting to the learning task. In similar results on the effect of context, Prins et al. (2008) used authentic practice as contexts for learning (using chemical modelling to teach about the nature of models) and conclude that not all authentic practices are suitable and they need to be evaluated for suitability.

This discussion has illustrated the significant role context is known to play in learning in the sciences. A number of the studies noted here caution that a considered design of context is needed in order to achieve improved learning outcomes. Discussion of context in science learning in general may arguably be applied to laboratories in particular. Hofstein and Lunetta (2004) explain that laboratories can provide opportunities for contextualised learning that are in line with current constructivist views that students construct knowledge though solving meaningful problems. For this research a focus will be put on context and how it may improve laboratory learning outcomes.

2.3.3 Context in Laboratories

Some research indicates that contextualising a laboratory may have a positive effect on student's attitude towards labs, perceptual recognition, memory recall and information interpretation (Godden & Baddeley, 1975; Liu, 2006; McElhaney & Linn, 2008; Pringle & Henderleiter, 1999). However, domain context in laboratories has only been addressed to a limited degree in the literature. It has been identified that future work into the effectiveness of laboratories in meeting learning outcomes should involve careful consideration of the contextual details of the laboratory (Hofstein & Mamlok-Naaman, 2007).

As described in section 2.2.5, a laboratory can be considered a proxy for reality that allows establishment of the relationship between a theoretical model and reality. The nature of laboratories as representations of reality means that they always include domain context in some form. Traditionally, while laboratory guides provided to students might include some domain context (such as an illustrative scenario), the laboratory apparatus itself is often sitting on a stark lab bench removed from the context in which the concepts being studied might normally exist. While the argument could be made that removing distractions allows a focus on the core elements of the experiment, there is little research in the literature of the effect of this context-poor presentation. The lack of context is more likely to arise from the logistical or budgetary difficulties of providing a rich context, than from a clear pedagogic basis.

A laboratory activity is an example of 'learning by doing' and therefore Yang's (2003) 'contextualisation' learning mode (which transforms explicit knowledge into implicit knowledge). Laboratories provide a specific use case (or domain context) for a model under study facilitating a change to implicit knowledge.

As mentioned above, Klassen (2006) describes context in learning as including practical, theoretical, social, historical and affective context. The practical context in the sciences would be apparent in laboratory work. Klassen suggests that practical tasks, rather than being 'atomised' into discrete stand-alone tasks, should be given a greater degree of contextualisation, supporting the concept of contextualised laboratory activities. Klassen's further aspects of context may also be applied in a laboratory activity. Students' motivation is often linked to the authenticity of the situations and experiences of the student which can be enhanced within a laboratory. Theoretical context, which Klassen argues emerges through investigation, replaces the traditional text book examples found in science education. Theoretical context should be combined with practical context for 'well-rounded' learning.

In order to determine how context can be used to meet the requirements of chemical education curricula, Gilbert (2006) describes four models of how context is typically used and assesses each of these according to how well they meet the four attributes of context (setting, behavioural environment, specific language and relationship to existing knowledge as described above as *Attributes A-D*). In conclusion, the following models progressively support context based learning:

1. *Context as the direct application of concepts:* the application of concepts to real world examples after teaching the concept. This implies a one-directional relationship between content and context. This model does not support context based learning well.
2. *Context as reciprocity between concepts and applications:* rather than a 'post-hoc' use case, this model situates the learning in a context so that the relationship between context

and content can be seen to work in both directions. This models supports context based learning but does not address the 'setting' (Attribute A) and has limited success relating the content to students' existing knowledge (Attribute D) .

3. *Context as provided by personal mental activity:* this is exemplified by a model in which the learning activity consists of three elements: 'situation', 'context' and 'narrative'. Situations embedded in a narrative which are meaningful to the student, enable students to build on their mental models in order to better understand the content as well as aid in transferring the new knowledge to other situations.
4. *Context as the social circumstances:* based on situated learning and activity theory, this model involves the context being a social surrounding or social activity in which learning takes place. This best meets the criteria for context based learning to be achieved.

If these four models are considered for typical laboratory activities the progression could be from laboratory equipment and 'cook-book' lab guides administered after concepts, through labs that have supporting documentation and meaningful assessment of learning, onto labs that include a meaningful narrative as part of the activity, and finally an immersive or 'real-world' context as a laboratory activity. In a typical undergraduate laboratory, the third model should be achievable with a suitably designed situation, context and narrative.

Considering Novak's (1976) cognitive bridge in a laboratory setting, it can be argued that explicit domain context can, in effect, act as a cognitive bridge, priming the learner to make associations between the laboratory concepts that are evidenced in the experiment, and broader concepts in the scientific domain being explored and which are part of the learners existing knowledge, but which are not explicit in the experiment. Often the associations provided within a laboratory are the result of analogical reasoning (Gilbert, 1989). For example, a deforming beam in a physics experiment might be described analogously as a bridge across a river, thereby priming the student to think of a load on the beam as a car crossing that bridge.

Regarding a provided context as a form of cognitive bridge is useful in that the research can then draw on the insights provided by Ausubel and Novak in relation to the design of these cognitive bridges and therefore for the design of the context for laboratories. That is, that the advanced organiser be at a 'higher level of abstraction' than the content being studied, and comparative organisers should help differentiate between new and existing knowledge (Ausubel & Fitzgerald, 1961). Cognitive bridges should identify the key concepts and their relationship to existing knowledge (Novak, 1976).

The review has uncovered research on the relationship between context and the content under study, the type of information that context should supply and how context should be represented.

Frameworks exist that may be used to analyse context, but these focus on the relationship between context and the learner (Tessmer & Richey, 1997), or context and the cognitive processes involved (for example Klassen's (2006) SDCA) and none give a clear indication on what elements could or should make up domain context, particularly for laboratories. In addressing this shortfall, it is useful to look at current implementations of contextualised laboratories.

2.3.3.1 Examples of Contextualised laboratories

While laboratory equipment by itself will provide some form of domain context, there are examples in the literature where laboratories have been enhanced with further contextual information. Domain context has been added to labs in a number of ways, for example: visualisations (McElhaney & Linn, 2008; Gilbert, 2008); questions as context-generating prompts (Demetriadis et al., 2008); analogies and metaphors (Gilbert, 1989); 'real-life' scenarios (Pringle & Henderleiter, 1999); combining different forms of laboratories (Liu, 2006); or using virtual worlds to create new environments (Back, Kimber, Rieffel, & Dunnigan, 2010; Callaghan, McCusker, Lopez Losada, Harkin, & Wilson, 2012). In these studies, the contextualisation of the laboratory is not always the intention or focus of study, but by changing the nature of the laboratory activity, domain context has been added.

Examples of laboratories that have been explicitly enhanced with contextual information, or where the laboratory itself is used to provide such context to a learning activity, are presented in the literature. Barab and Dede, 2007 have developed a game-based learning environment that includes embedded and embodied 'formalisms'. The laboratory consists of a water quality simulation in a three-dimensional virtual environment allowing students to navigate through the virtual world, interact with other students and characters in the world and to perform tasks. They propose that, through participating in the activity, the formalism are contextualised for students, and with reflection, abstracted. Barab et al. (2007) aim for a 'situative embodiment' in their curriculum which includes not only the elements that student perceive, but a story line as well.

Pringle and Henderleiter (1999) add domain context through the use of 'real-life' scenarios as a modification to existing chemistry laboratories and show improved student attitudes. Abdulwahed et al. (2008) enriched engineering lectures by using remote laboratories to provide domain context within a classroom lecture, also finding improved attitudes. McElhaney and Linn (2008) introduced an activity including the visualisation of an airbag deploying to investigate how experimenting with visualisations affected students learning outcomes. (They found that learning improved most in students who could most successfully conduct valid experiments with the visualisation.) Mckagan et al. (2008) describe how associating science with real world examples and contexts was used in the design of their Physics Education Technology (PhET) simulation laboratories to engage students and support their learning of quantum mechanics.

Other examples of contextualised laboratories are described in the literature where the provision of domain context is incidental to the research aim, for example a mixed reality Virtual Chocolate Factory was developed which allowed trainees to learn about machines in a mock factory environment (Back et al., 2010), and Callaghan et al. (2012) use an immersive virtual world to implement game-based learning for electronics, providing additional domain context through the game environment.

2.3.3.2 Context and Laboratory Learning Outcomes

The literature strongly supports the view that context has an effect on learning, but the discussion in terms of specific learning outcomes for laboratories is limited largely to increased engagement and improved attitudes. There is research to show that changing the mode of the laboratory affects learning outcomes, and that the interface to a lab will have an effect as well as the format of the lab guide and assessment (Lindsay & Good, 2005; Nickerson et al., 2007). From a learning approach, scaffolding laboratory activities with suitable domain context that includes representations of reality that cannot be directly drawn from the model would have an effect on Kokinov's (1999) perception, memory recall and reasoning processes which create context for the student and thereby have an effect on the learning outcome of the laboratory

Looking at how adding domain context can be expected to affect specific laboratory learning outcomes, it is useful to consider Gilbert's (2006) description of how context can address problems in science education (described above). Most relevant of these are the ability to focus attention on important concepts, support students' understanding of relationships between facts, and make the transfer of knowledge 'more likely'. Looking at each of these, the value added by context can be expressed clearly:

- *Focus attention on important concepts*: in a laboratory activity context can highlight the purpose of the laboratory and illustrate where it applies and possibly where it is 'importantly wrong'.
- *Support understanding of relationships between facts*: in a laboratory, which is a proxy for the real world, a critical relationship is the link between the model under study, the laboratory and the real world. Both the laboratory and the model under study are partial representations of reality whose relationship is not always obvious within a lab activity.
- *Improve knowledge transfer*: laboratories are designed to teach concepts in one domain

that will be required to be recalled and applied in other domains. Specifically, application of the content under study in the laboratory to a real-world scenario.

These benefits of domain context within a laboratory activity have the potential to help students identify the function of the laboratory and to improve students understanding of how the model being investigated relates to the real world. As described in sections 2.2.1 and 2.2.5, students often have difficulty with understanding the nature of models and with effectively using laboratory activities as a tool to learn those models. Looking back at Figure 2.7, it is proposed that the benefits that can accrue from adding domain context to the laboratory activity can help students understand the three way relationship between the model, laboratory and the real world, and in doing so affect the ABET learning outcome concerning models. This has been proposed and discussed through an example in Machet, Lowe, and Gütl (2012).

The concepts presented here will be summarised (in section 4.2) and used in this research to design contextual information for a laboratory activity (see section 4.3).

2.4 Virtual Learning Environments

Virtual environments are becoming commonplace in entertainment, social interaction and increasingly in education. The literature shows that as technology improves the *quality* of virtual environments, in line with *increased availability and advancements* in broadband, wireless computing, video and audio technologies, the topic of how virtual environments may be used in education has drawn growing attention (Dalgarno & Lee, 2010; Warburton, 2009; Chang, Gütl, Kopeinik, & Williams, 2009).

As reported by Dalgarno (2002) there are a range of terms used to describe virtual learning environments, each of which is ambiguous and includes a broad range of scenarios. For example, learning in a virtual environment can consist of desktop virtual worlds or sensory immersion such as haptic feedback devices and head mounted displays. For this research, based largely on practical considerations of providing the technology to a large cohort of students within a university, the focus is on virtual learning environments accessed through desktop computers. Specifically, this research is looking at three-dimensional (3D) environments, referred to here as ‘virtual worlds’, rather than, for example, environments such as learning management systems (Blackboard, Moodle etc.). In Dalgarno and Lee (2010), the most important distinguishing characteristics of 3D virtual learning environments are identified as ‘three-dimensionality, smooth temporal changes and interactivity’.

2.4.1 Types of Virtual Worlds

Virtual worlds have been in existence since the 1980s, initially based on multi-player games and the subsequent massively multi-player online games (MMOs) (Warburton, 2009). Warburton (2009) provides a detailed analysis of the history and current use of virtual worlds in education. According to Warburton, what distinguishes a virtual world from MMOs is their open-ended nature. It is this feature that appeals to educators: rather than providing a predefined narrative in which users interact, virtual worlds provide only the environment allowing users to create content and decide on the nature of the activities and interaction.

There are a large number of virtual worlds available, both as open source and proprietary platforms, each developed for a variety of purposes and with a different focus. Proprietary examples include Second Life, Active Worlds and Twinity (Warburton, 2009; Thompson, 2011). Open source examples include Open Wonderland and OpenSimulator (which is an open source virtual world similar to Second Life) (Thompson, 2011). Warburton (2009) describes one of a number of typologies that exist for virtual worlds which is based on the virtual worlds' 'narrative approach' and the representations that they entail:

- *flexible narrative*: typically games which have flexible narratives within the rules of the virtual world;
- *social worlds*: intended for social interaction and include fictional and real world elements (such as audio);
- *simulation*: representations of the real world;
- *workspace*: computer supported collaborative work spaces in a 3D environment.

These definitions are not exclusive or clear-cut and one virtual world platform may be classified into more than one category depending on its application. The literature describing projects done within virtual worlds also indicates that there is often not a single virtual world that will fulfil all the requirements for a project (Back et al., 2010).

As described in Machet and Lowe (2012), literature already exists evaluating and comparing virtual world platforms from differing points of view. Warburton (2009) assesses the affordances and barriers to the use of Second Life as a teaching tool and describes its popularity and limitations in terms of its technical, immersive and social aspects. Gardner, Scott, and Horan (2008) discuss the choice of Open Wonderland over other virtual worlds (such as Second Life and OpenSimulator) due to, amongst other factors, its live application sharing ability, and its open and extensible nature. Others have examined virtual worlds by comparing the collaboration and communication tools of the different platforms (Wynne, 2010; Zutshi & Sharma, 2009). There are many additional sources that both implicitly and explicitly compare virtual world while describing or creating virtual world implementations (Dickey, 2003; Back et al., 2010; Boulos, Hetherington, & Wheeler, 2007; Garcia-Zubia et al., 2010; Dickey, 2005). Anecdotally, users of the different platforms similarly argue the different merits depending on the use case (for example Davenz, Kpr777, Micheldenis, Matty_x, and Technobuddhist (2008)).

These sources provide no consensus on which virtual world platform is most suitable for use in education in general. Rather, they each provide advantages and have barriers to effective use. As an example, Garcia-Zubia et al.'s (2010) implementation of a remote laboratory set in Second Life (SecondLab) proved its feasibility but concluded that Second Life is not recommended due to its limited scripting language (the proprietary Linden Scripting Language (LSL)), provision of few interface components, the memory restrictions on LSL script sizes and a lack of high level protocols. In contrast, Callaghan, McCusker, Losada, Harkin, and Wilson's (2013) implementation of labs in Second Life was successful and made use of the features such as Second Life's support for the Moodle LMS.

2.4.2 The Role of Virtual Worlds in Learning

The potential for virtual worlds to deliver on educational outcomes is described in the literature in terms of the 'affordances' of virtual worlds. The term *affordance* refers to characteristics that facilitate certain behaviours (Dickey, 2003).

Dalgarno (2002) provides a theoretical justification for the use of 3D virtual learning environments on the basis of three constructivist approaches to learning (namely Moshman's endogenous, exogenous and dialectical constructivism). He identifies that empirical research into the effectiveness of 3D environments is needed in order to strengthen arguments in support of their use. Girvan and Savage (2010) conclude from their study that 'communal constructivism' is supported by the affordances of Second Life. Virtual worlds' ability to provide a constructivist learning environment is supported by Dickey (2003) as a result of the 'discourse, experiential, and resource tools' they afford. Coffman and Klinger (2007) also emphasise that use of a 3D virtual worlds can support a constructivist approach to learning by providing authentic problems that students can relate to.

In later research, Dalgarno and Lee (2010) present a framework for the study of learning in interactive 3D virtual worlds describing these potential learning tools as affording the ability to:

1. develop enhanced spatial knowledge;
2. learn tasks that may be impractical or impossible in the real world;

3. design tasks that result in increased motivation and engagement;
4. contextualise learning, thereby improving transfer of knowledge and skills to real situations;
5. allow for collaborative learning that is richer (and possibly more effective) by facilitating collaborative tasks not possible with 2D options.

The fourth affordance (to contextualise learning) is based on the ability of 3D virtual worlds to provide 'realism and interactivity' that more closely represents the real world so that knowledge learnt in the virtual world environment is more easily applied in the real world (Dalgarno & Lee, 2010).

Chapman and Stone (2010) support the inclusion of contextualisation of tasks as an affordance of virtual worlds and describe specifically that 3D virtual worlds can support a link between theory and application of learning by 'providing a real-life context for knowledge application'. Warburton (2009) identifies visualisation, contextualisation and simulation of otherwise inaccessible content as an affordance of the Second Life virtual world. Oloruntegbe and Alam (2010) too identify that one of the strengths of using 3D virtual worlds in education is the ability to model abstract concepts so that they are 'tangible' for students and can help to bridge the gap between the real world and abstract concepts and models. Savage, Mcgrath, Mcintyre, Wegener, and Williamson (2010) report that using 3D interactive virtual worlds can improve students understanding of abstract physics concepts. Through the use of an interactive 3D virtual world to teach relativity to undergraduate students, they found that those students who used the simulation found the concept of relativity 'less abstract'.

Chambel et al. (2004) describe how hypervideo (a video stream with embedded, user-clickable links) may allow for the construction of mental models and transfer of knowledge by 'replacing' real experience (because of their authenticity), allowing visualisation of dynamic processes not otherwise observable and by combining different modes of communication (such as text, pictures or audio) into a meaningful message. These three factors can also be facilitated within virtual worlds.

Dalgarno and Lee (2010) conclude from a review of the research into learning in 3D environments, that there is no consensus on whether learning benefits (if found) are attributable to the 3D learning environments themselves. This is supported by the extensive review conducted by Oloruntegbe and Alam (2010) who, while finding some evidence of learning improvement, found most of these to be in the area of improved affective domain and could not find support for the pedagogic value of 3D learning environments.

Dalgarno and Lee (2010) suggest that it is the tasks and activities conducted in the virtual world that may result in learning, not the virtual world itself. While acknowledging that there is currently debate over the pedagogical value of 3D virtual worlds, this research does not propose that learning benefits will accrue due the 3D environment itself, but rather suggests that making use of an identified affordance of virtual world may prove of benefit, that is, the ability to contextualise learning. The following section considers this in terms of what it may mean for laboratory activities.

2.4.3 Laboratories in Virtual Worlds

The ability of 3D virtual worlds to add context to a learning activity allows educators to augment a laboratory with domain context. The virtual world can be used as a tool to enhance the laboratory with contextual elements. As the laboratory is a proxy for some aspect of the real world used to investigate a model, this domain context may assist students to understand the connection between the model, laboratory and the real world. In support of this Corter et al. (2011), in looking at ways to improve remote lab and simulation interfaces, suggest that 'multimedia explanations and graphic feedback to the experiment' could aid students' understanding or that providing multiple representations in the experiment could assist in developing student understanding for complex concepts.

The affordance of virtual worlds to provide a link to reality in a way that is not possible or is highly impractical otherwise has been used as the basis for the design of a number of educational 3D virtual world laboratory environments including a wide range of simulation laboratories (Chen, 2010). The Quest Atlantis project is set in a proprietary virtual world and was used to investigate the potential of situationally embodied curriculum (Barab et al., 2007). Another simulation lab in a proprietary virtual world is the Puget Sound project which looked at how an immersive virtual learning environment may affect students' conceptual understanding (Winn, Windschitl, Fruland, & Lee, 2002). Of interest in Winn, Windschitl, Fruland, and Lee's (2002) conclusions is that they would recommend the cost of implementing an immersive virtual environment is only justified 'when the content to learn is complex, three-dimensional and dynamic, and when the student does not need to communicate with 'the outside' while working.'

Dalgarno (2002) describes the use of a virtual chemistry laboratory within a 3D virtual world for distance education students. The work showed the virtual laboratory to be effective in familiarising students with the real laboratory environment and later work illustrated students' positive attitude to the environment (Dalgarno, 2012). Adding simulations of otherwise invisible phenomena such as field lines has been done by Pirker, Berger, Gütl, and Belcher (2012).

Scheucher et al. (2009), having identified problems that physics students have in relating theory to the real world, demonstrated the feasibility of setting a remote laboratory (and the field line simulation described in Pirker, Berger, Gütl, and Belcher) in a virtual world.

For this research a distinction is made between simulations and remote laboratories, so it is of interest to look particularly at how real equipment has been integrated into virtual worlds.

2.4.3.1 Real Equipment in Virtual Worlds

When considering the interaction between the real and the virtual there exists a spectrum of interaction that ranges from the real world to a purely virtual world. Along this spectrum are 'mixed reality' systems that have aspects of the real world and virtual entities combined in some way (Milgram & Colquhoun Jr., 1999; Machet & Lowe, 2012). Mixed reality systems may take the form of 'augmented reality' whereby the virtual elements are integrated into a real environment in real time (such as a head mounted display that can superimpose a new proposed building on a street-scape to see how it would look) (Azuma, 1997). Alternatively, mixed reality may take the form of a virtual world in which the world is completely modelled, but real data has been included in parts - 'augmented virtuality' (Milgram & Colquhoun Jr., 1999). An example of this might be a meeting room in a virtual world that has live video of meeting attendees superimposed on the chairs. This research is concerned with how real equipment from a laboratory may be integrated into a virtual world, or a type of augmented virtuality.

The Intelligent Systems Research Center at the University of Ulster has done much work in the area of integrating real equipment into a virtual world (Callaghan et al., 2012; Callaghan, McCusker, Losada, Harkin, & Wilson, 2013). They selected Second Life as a virtual world and developed a number of systems that link real hardware to the virtual world and track (in the Moodle LMS) the results of any interaction. One such integration is that of a physical washing machine simulator being linked to a virtual replica of the simulator in Second Life (Delacoux & Perrin, 2009). Changes to the real (i.e. physical) washing machine simulator are reflected in the virtual simulator, and any changes made in the virtual world must follow the logic of the real simulator and be communicated to the real washing machine simulator. While there are reported limitations to the control from both the real and virtual washing machine simulators, the technical integration of real equipment into the virtual world was shown to work effectively (Delacoux & Perrin, 2009; Machet & Lowe, 2012).

A larger project from the group involves a games based laboratory aiming to teach students electrical and electronic theory. The Circuit Warz lab is set within Second Life and consists of students forming teams, taking quizzes and competing in designing oscillator circuits. The circuits are displayed graphically in the virtual world with a schematic circuit diagram, but are linked to real hardware (though the students do not see this hardware). The changes students make in the virtual world are executed with real hardware and the results fed back to the virtual world (Callaghan et al., 2012).

These research examples demonstrate the technical feasibility of real equipment being integrated into Second Life, with control from the virtual world to the real equipment, and feedback from the real equipment to the virtual world possible too.

In research that is closely related to this research project, Scheucher, Belcher, Bailey, Fabio, and Gütl (2009) set a remote electromagnetic laboratory within the Open Wonderland virtual world and augmented the display with an emulation of the electromagnetic field lines. Their study aimed to determine whether the collaborative and immersive affordances of virtual worlds had an effect on learning outcomes. The students had access to the remote 'force on a dipole' laboratory controls and a video of real equipment as well as a virtual representation of the experiment showing (otherwise invisible) field lines. There is no direct communication between the hardware and the virtual world, but Open Wonderland allows the existing remote laboratory control interface and simulation to be embedded within the virtual world.

Further case studies in the literature illustrate that Open Wonderland has been used to integrate different existing remote laboratories into virtual worlds with no substantial additional costs other than the server (Fayolle, Gravier, Yankelovich, & Kim, 2011). There are also individual user projects that include Open Wonderland interfacing directly with hardware such as the Microsoft Kinect (Schmidt, 2011; Flores, 2011). These projects prove the feasibility of two way communication between Open Wonderland and the real world.

As other examples, the GCAR-3DAutoSysLab (Pereira, Paladini, & Schaf, 2012) has been integrated into OpenSimulator and the Virtual Chocolate Factory (a mixed reality chocolate factory) has been trialled on Open Wonderland and OpenSimulator among others (Back et al., 2010). Marcelino et al. (2010) describe a remote elasticity laboratory set in OpenSimulator and including the virtual world learning management tool Simulated Linked Object Oriented Dynamic Learning Environment (Sloodle). There has been recent work integrating the Microsoft Kinect in Open Simulator too (Cassola, Morgado, de Carvalho, Paredes, & Fonseca, 2014).

There has been work done on standardising an interface between virtual worlds and real equipment. Syamsuddin, Lee, and Kwon (2009) defined a 'virtual world and real world interface'

(VRI) that aims to bridge any virtual world to a range of ‘interaction devices’ such as joysticks, or a Wiimote.

The range of implementations, experiences and research outcomes in the literature indicate that it is technically feasible to integrate real hardware in general, and remote laboratories in particular, into a range of virtual worlds. However, there is no consensus on which virtual world is most suitable for interfacing to real equipment. This is in line with the finding that no virtual world is considered ‘best’ for education in general. The decision of which world should be used in this research will need to be made with reference to the specific requirements of the integrated system.

The literature on 3D virtual worlds has established that they afford the ability to contextualise learning activities and that it is feasible to use them as a tool for providing context to remote laboratories. The following section of the literature review will look into details necessary for the comparison and selection of the virtual world platform to be used in this research.

2.4.4 Evaluating Virtual Worlds

Of the existing applications of laboratories in virtual worlds mentioned in this literature review, most make use of either proprietary, built-for-purpose virtual worlds (such as the Virtual Chocolate Factory and Puget Sounds examples), Second Life, OpenSimulator or Open Wonderland. The development effort available for the research project excluded the possibility of developing a proprietary virtual world for the study, so the remaining three virtual worlds most accepted in the literature have been analysed and will be assessed in terms of which best meets system requirements in Chapter 5.

This research will include the integration of an iLabs based remote radiation laboratory into the Open Wonderland virtual world. Justification for the choice of these components is included in sections 4.1 and 5.2.1. This section reviews the functionality and features of Open Wonderland (Open Wonderland Foundation, 2015, ‘Features’), Second Life (Linden Research, 2015, ‘Second Life Quickstart’) and OpenSimulator (Overte Foundation, 2015, ‘Features’). It also provides the background information on the architecture of Open Wonderland.

2.4.4.1 Open Wonderland

Open Wonderland is an open source virtual world developed by Project Open Wonderland. It is a Java based platform that is extensible and free. Open Wonderland is simple to install and is a stable platform under active development. It has a community of developers continuing to develop and incorporate community member code. Support and documentation is available from this community. The development installation of Open Wonderland allows for changes to the platform code and the implementation of a wide range of new features.

The Open Wonderland client can run on a range of platforms and an Open Wonderland server installation can be configured as a stand-alone server behind a firewall. It supports authentication creating a secure environment. Open Wonderland requires a number of TCP and UDP ports to be open from the server to function correctly (Parsons & Stockdale, 2010).

In terms of interfacing with the real world, Open Wonderland allows shared applications and supports multiple language plug-ins. The VNC viewer tool, for example, could allow control of a desktop hosting a remote laboratory control interface such as LabView (Scheucher et al., 2009). Any X11 (Linux) applications can run in Open Wonderland. The ability to re-use existing control interfaces in Open Wonderland with application sharing provides a simple mechanism to control real equipment that has an existing control interface. Additionally, the modular nature of Open Wonderland means that modules developed to interface to external devices can be freely used (such as the Microsoft Kinect avatar control module, or the REST interface module). This means that there can be low cost, relatively rapid deployment of laboratories where control applications already exist. Adding behaviours to content elements in Open Wonderland is achievable through its support of Java and plug-ins for scripts in multiple languages (Machet & Lowe, 2012).

Considering the creation of content, Open wonderland allows for the easy importation of existing content in numerous file formats (drag and drop images, documents, animations etc.). There are models available for free, as well as 3D models that can be purchased.

Open Wonderland does not have a sophisticated physics engine, so while it supports collision detection, more complex physical phenomenon would have to be achieved through the use of a physics engine plug in (Yankelovich, 2009) or developed specifically for the object.

Open Wonderland can support live video streaming so that students would be able to see a video of the actual equipment during the laboratory execution. It also supports a large variety of collaboration tools such as notes, chats and document sharing.

2.4.4.2 Second Life

Second Life is a very stable, well supported and widely used platform which is ahead of the other platforms in terms of stable releases (Open Wonderland and OpenSimulator are on releases 0.x).

The Second Life client can run on a number of platforms however the server is hosted by Linden Lab. It is proprietary software that requires developers to buy ‘land’ to develop and only supports the proprietary Linden Scripting Language (LSL).

Existing Second Life implementations for interfacing to external hardware are not available to be re-used but documentation exists where the integration of real equipment has been done as part of a research project. Second Life has been shown to have limited support for high level protocols to interface to external software (Garcia-Zubia et al., 2010).

Concerning the rendering of a laboratory control interface, Second Life does not support the same type of application sharing that is available in Open Wonderland, however controls can be rendered and replicated in the virtual world that are similar to the real world at a cost of time and effort, or they can be purchased.

Second Life can add contextual information in the form of imported objects but supports only a limited number of formats. There is a large amount of existing objects and elements that can be purchased for use in Second Life which means that a rich realistic context could be created. However, adding behaviours to this content must be done using the proprietary Linden Scripting Language and the limited size of scripts makes development complex.

Second Life has the Havok physics engine which is a more sophisticated physics engine than Open Wonderland. It also supports video streaming for live remote lab video.

Usefully for educational applications, Second Life has a Moodle module, Sloodle, that merges the virtual world with the online learning environment and is very useful for tracking and evaluating students work within the virtual world.

2.4.4.3 OpenSimulator

OpenSimulator is an open source, though not Java based, virtual world and can be considered as the ‘open source version’ of Second Life due to its support for Second Life viewers and LSL. OpenSimulator is a stable platform (though still on release 0.8) and development is continuing with new features being released to keep in line with Second Life and to extend its functionality. A development installation allows platform and functionality changes more in line with Open

Wonderland than Second Life.

Similarly to Open Wonderland, the OpenSimulator client runs across multiple platforms and a stand-alone server can be installed behind a firewall.

Work is only recently reported in the literature for integrating equipment into OpenSimulator such as the Microsoft Kinect (Cassola et al., 2014). As for Second Life, OpenSimulator does not support application sharing but laboratory controls can be rendered and replicated to look very realistic in OpenSimulator. OpenSimulator supports LSL and its extension OpenSimulator Scripting Language as well as C#, so, while more flexible than Second Life, it is more restricted than Open Wonderland.

OpenSimulator, too, supports live video streaming.

2.4.5 Existing Architecture: Open Wonderland

Open Wonderland is an open source virtual world developed by Project Open Wonderland. One of the major goals of the Open Wonderland developers was the provision of an extensible toolkit based on open standards to enable easy development (Kaplan & Yankelovich, 2011).

Open Wonderland has a modular client-server architecture developed in the open source Java programming language. As described in Kaplan and Yankelovich (2011), the client provides a browser showing the 3D environment. Communication between the client and server uses a number of different network protocols, each of which is selected as optimal for the specific data type, for example web services for authentication and downloading and multimedia streaming for video and application sharing.

The server consists of four services:

- a *Web Administration Server* which serves as a central management console for all services;
- the *Darkstar Server* which is a low latency server designed for gaming and used to track the state of live objects in the world;
- the *JVoiceBridge* which is a Java application for server-side mixing of audio;
- and the *Shared Application Server* which runs on Linux or Solaris systems allowing sharing of server hosted applications.

These are illustrated in Figure 2.8.

The Wonderland toolkit allows developers to extend Open Wonderland at a number of different

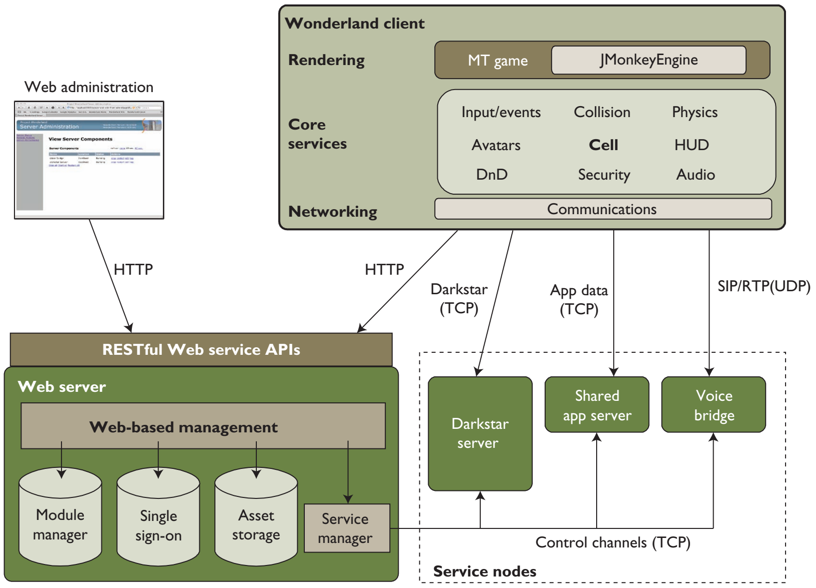


Figure 2.8: Open Wonderland network diagram (Kaplan & Yankelovich, 2011)

'extension points.' A common extension is a new object type referred to as a cell. A cell is a three-dimensional space that is an independent Java object that can have both client and server behaviour. For example a cell can include the function of rendering an object in world, can handle reactions to user inputs, and/or can send or receive messages from the server or client. A cell may contain other cells in order to form a cell tree.

The Open Wonderland project provides the infrastructure to create and add new modules, where new cell types can be developed and compiled. There are a number of modules in the Open Wonderland Module Warehouse that have already been developed that can be easily included within a new virtual world, such as video streaming. One such module provides in-world scripting capabilities which supports a number of programming languages and can be included in new cells. This scripting is useful for animating a model in-world or for inter-cell communication.

Currently there is no SOAP module for Open Wonderland, but there are a number of solutions for external communication, such as a module that provides an example of a RESTful API to a web service (Flores, 2011).

The literature reports examples of laboratories and real equipment integrated into Open Wonderland Scheucher et al. (2009); Fayolle et al. (2011); Schmidt (2011). Open Wonderland has an active and very supportive development community and much documentation available on how developers can make use of the platform.

2.5 Chapter Summary

This literature review has presented the state of the art on laboratories, models, context and virtual worlds as used in learning in the sciences. Through this review the relationship between these concepts has been clarified. In summary, the findings that this project draws on are:

- Laboratories, models and the influence of context are ubiquitous in science learning and each play an important role in the learning process and students' learning outcomes.
- Laboratories can be considered as proxies for the real world which are used to investigate underlying theoretical models. It is important, therefore, to understand the three way relationship between laboratories, models and the real world.
- An identified learning outcome from laboratories that has not been fully addressed in the literature is the understanding of models and their strengths and limitations as predictors of real-world behaviour. Both models and laboratories are only partial representations of the real world and therefore the relationship between laboratories, models and the real world is not trivial.
- Remote laboratories and virtual worlds are increasingly used as tools in science education, but there is much scope to investigate their potential impact on a range of learning outcomes.
- Remote laboratories are mediated through a computer interface providing an opportunity to easily manipulate the laboratory interface. While research indicates that the mode of the laboratory has an effect on learning outcomes, remote laboratories have been shown to be effective in meeting a range of learning outcomes and the targeted learning outcomes should be considered when selecting the remote mode for a lab activity.
- Contextualising learning has been shown to help with conceptual understanding, relating new content to existing knowledge and with the transfer of knowledge to new domains. The literature indicates that contextualising learning may help in learning about and from models. While there are examples of contextualised laboratories, there is limited research into the effect of the contextualisation on specific learning outcomes, especially when they concern models.
- Domain context for a laboratory has been defined as those elements of context that relate to the model under study. The literature includes indications of the role and the nature of the elements that should make up domain context, but there is no clear indication of what constitutes effective domain context for a laboratory.
- Virtual worlds afford the ability to contextualise a learning activity.

The literature indicates that there is reason to believe that contextualising a laboratory will have an effect on learning outcomes, and particularly that the learning outcome concerning models may be affected. That is, adding domain specific contextual information to a laboratory activity has the potential to improve students understanding of how the laboratory relates to the real world it is attempting to model. The contextual information should aid in developing an understanding of the underlying theory being taught and how it can, or cannot, be applied in the real world. In looking to effectively contextualise a laboratory, remote laboratories provide a pedagogically sound environment and a conveniently mediated interface. Virtual worlds allow the creation of a rich context.

The literature review has uncovered related work that covers many of the topics addressed here. Namely, research that has considered how models can be positioned within science education (Gilbert et al., 2000; Gilbert, 2004), the relationship between models, theory and reality (from a constructivist point of view) (Gilbert et al., 2000), contextualising science education (Gilbert, 2006) and using visualisation as method to develop an understanding of models (Gilbert, 2008). That research underpins the discussion on how context, models and laboratories are used in science education while not specifically describing an empirical study combining the concepts.

Also found through the literature review was similar work having been done by Winn et al. (2002) (investigating conceptual change in the Puget Sound immersive virtual world), Barab et al. (2007) (investigating a situationally embodied curriculum using a virtual world), Mckagan et al. (2008) and Adams et al. (2008) (using context as a design factor in their PhET simulations), Callaghan et al. (2013) (looking at the effect of a game-based laboratory activity) and Scheucher et al. (2009) (looking at a solution for integrating remote labs into virtual worlds). These reports all assist in defining exactly where the gap in knowledge exists. The contributions have been discussed in more detail the previous sections in this literature review, but their research focuses either on the affordances of virtual worlds, such as immersion, or the effect of the game based nature of the activities, with no specific mention of the context. Where context was reported as a design factor, the research involved simulations (rather than remote labs) and the research did not look at the effect that the contextualised environment had on students' understanding of the relationship between the underlying theoretical model and the real world.

The potential effect that contextualising a laboratory by setting a remote lab in a virtual world may have on students understanding of models has not been explored in the literature but it has been argued that it may improve students' ability to identify the strengths and limitations of models as predictors of real world behaviour. It is proposed that this research address this gap in knowledge.

Chapter 3

Research Approach

This chapter describes the approach and methodology that was applied in this research.

As detailed in Chapter 2, the literature has been researched and a gap in current knowledge has been identified. In this chapter, the gap in knowledge is expressed as a hypothesis and a testable null hypothesis is drawn from this. The approach taken for this research is to break down the hypothesis into research questions. The answers to the research questions form the basis of this research. To arrive at answers to each of these research questions different research methods are needed. For this reason the research questions are categorised and the research methodology that is to be used to address each group of questions is described.

The first section in this chapter deals with the hypothesis. The following section describes each of the research questions arising from the hypothesis and classifies them according to the methodology that can be used to address them. This results in the identification of four major tasks that need to be completed in order to complete the research.

The literature on suitable methodologies is reviewed and the selected methodology which was used to arrive at answers for the research questions is then outlined and justified for each of these tasks. Finally, the research methodology is summarised and conclusions about the research approach and selected methodologies are described.

3.1 Research Hypothesis and Null Hypothesis

As described in section 2.5, the literature review has identified a gap in knowledge to be addressed by this research.In summary, the literature review has described the importance and ubiquity of laboratories in science education and the importance of students understanding the models they investigate, particularly their strengths and limitations as predictors of real-world behaviour. It is well acknowledged in the literature that a student's learning is affected by their context and that different learning objectives can be enhanced by contextualising learning. It is reasonable to question whether extending a laboratory to include representations of elements of the real-world that extend beyond those directly drawn from the model may have a significant impact on students' learning.

The literature review has shown that the emergence of remote laboratories, and therefore the ability to mediate the interface through which the laboratory is accessed, has created an opportunity to provide enriched laboratory contexts. Virtual worlds are used extensively in education because of, amongst other aspects, the ability to create a context and allow the user to see and interact with a world to which they may not otherwise have access. Virtual worlds can be used to create these contexts, and hence to assist students in understanding the relationship between models and reality.

The literature as described in section 2.5 provides examples of contextualised laboratories conducted in virtual worlds and presents conclusions concerning collaboration and engagement with these environments. However, no literature was identified that investigated how contextualising laboratories that use real equipment may effect students' understanding of how the models they are learning relate to the real-world in terms of their ability to predict real-world behaviour.

This research investigates this gap in knowledge. Based on the above discussions, this research proposes the hypothesis:

> ***H* -** *Embedding a remote laboratory within a virtual world that presents domain context can improve students' ability to identify the strengths and limitations of theoretical models as predictors of real-world behaviours, over the ability developed using the same laboratory in a non-contextualised setting.*

Converting this hypothesis into a testable null hypothesis results in the following:

> H_0 - *Embedding a remote laboratory within a virtual world that presents domain*

context has no effect on students' ability to identify the strengths and limitations of theoretical models as predictors of real-world behaviours, over the ability developed using the same laboratory in a non-contextualised setting.

3.2 Research Questions

The research hypothesis above can be deconstructed to develop research questions. Answering these research questions is the core of this research. This section breaks up the hypothesis and describes each of the resulting questions. The research questions are then classified into a number of core concept areas which will be approached using the most suitable method.

3.2.1 'Embedding a remote laboratory within a virtual world...'

The learning affordances of remote laboratories and virtual worlds have been identified in the literature review. Integrating a remote lab into a virtual world provides a method for adding contextual information to a laboratory. Once the integrated system is developed, it opens up the possibility of future research into benefits to laboratory learning outcomes that can potentially be provided by virtual worlds. The literature review describes recent work in the area of combined virtual worlds and laboratories and identifies a range of technical solutions that will be investigated for this research.

Considering the available literature and the nature of the hypothesis, there are a number of research questions that can be drawn from this:

- Do virtual worlds provide a suitable mechanism for adding contextual information to a laboratory?
- How can a remote laboratory be accessed through a virtual world?
- What constraints does the technical implementation of the system impose on the laboratory activity and its learning outcomes?
- What factors resulting from the technical implementation can affect the learning outcomes of the laboratory?
- How will the influencing factors be controlled and/or accounted for in the empirical research study and research conclusions?

Amongst other considerations, the solution should not be prohibitively expensive nor too technically difficult to be realistically used in the future. Although this is not essential to proving the hypothesis, it is practically necessary for this research and for future work in the area.

3.2.2 '...presents domain context...'

This research proposes that contextual information which relates to the content of the laboratory, and which is not usually present in typical laboratories (either hands-on, simulated or remote access), can be used to assist students in identifying the strengths and limitations of models that are not obvious from conducting the laboratory activity alone. This may, for example, include aspects of the real world that are not present in the model, or that serve to illustrate that the model can be extended beyond the use highlighted in the laboratory.

For the research to provide useful results, contextual information that links the model to the real world it represents must be identified to be incorporated into the laboratory. Keeping in mind the learning objective being targeted, the additional material presented to students must aid in their understanding of the strengths and limitations of models. The research aims to develop some guidelines for the type of information that could be included in laboratories to affect results.

We can address this aspect of the hypothesis with the following research questions:

- What defines domain context?
- Given the laboratory selected, what kind of contextual information should be added?
- How should the contextual information be presented?
- Can general guidelines be proposed for the type of contextual information that may be presented?

3.2.3 '...student's ability to identify the strengths and limitations of theoretical models as predictors of real-world behaviours...'

This is the crux of the ABET learning objective defined as the target of this research. In order to target this learning objective, the laboratory is analysed in terms of its being a proxy for the real-world that is used to investigate the model under study. Students are required to understand that all models have limits to their applicability, often because of assumptions or simplifications used in deriving the models. Equally, students need to understand that often a model has much wider application than the specific scenario presented in the laboratory. Understanding these strengths and limitations of models in general and the model being studied in particular is an important part of laboratory learning.

The research questions that should be posed are:

- How could contextual information aid students in being able to identify the strengths and limitations of models as a predictor of real-world behaviour?
- How can improvements in students' ability to identify the strengths and limitations of models as a predictor of real-world behaviour be measured?
- What experiment would be suitable to test students' ability to identify the strengths and limitations of models as a predictor of real-world behaviour?

3.2.4 '...improve students' ability ... over the developed ability using the same laboratory in a non-contextualised setting.

Students' ability is a measure of the extent to which they meet the learning outcomes. The research methodology must cover the development of a suitable test of learning outcomes that can be administered to a treatment group and a control group.

The aim of this research is to show that improvements in learning outcomes can be made by setting the remote laboratory in a virtual world that has additional domain context.

The research questions that follow from this are:

- How will it be determined whether students' understanding has improved after completing the laboratory?
- Does students' understanding of models improve with the setting of the remote laboratory in a context-rich virtual world over the same laboratory in a non-contextualised world setting?
- Can future areas of research be identified?

3.3 Research Design

The literature on the research design for laboratory education research is presented here as a background for the selection of the methodology for this research (see section 3.4) and the discussion concerning the validity of the research results (see section 6.2).

Of interest in selecting a research methodology is how other research into laboratory learning outcomes has been conducted (some of which is addressed in section 2.1.5.1). In their review of research conducted in engineering education, Borrego, Douglas, and Amelink (2009) concluded that there is no 'best' research approach, rather the selected approach must be driven by the research questions being addressed. Interestingly, much of the literature comments that the effects found in educational research are often small (for example Borrego et al. (2009), Campbell, Stanley, and Gage (1963) and Norman and Streiner (2003)).

3.3.1 Empirical Investigation

The systematic review by Bennett et al. (2007) identifies criteria which indicate high quality research into context based education that can guide the research design and reporting for this project:

- the reliability and validity of the data collection methods should be established;
- the reliability and validity of the data analysis should be established;
- potential sources of error or bias that may result in alternative explanations for the findings of the study must be accounted for and eliminated where possible;
- the sample size should be sufficient;
- the control and experimental groups should be suitably matched;
- preferably data should be collected before and after interventions;
- attitude and/or understanding should be an explicit independent variable;
- appropriate assessment measures must be applied and researcher bias eliminated where the developer of the intervention is the same as the evaluator;
- as wide a range of measured outcomes as possible should be reported;
- the situation should be representative of a normal learning environment as it increases 'consequential validity'.

Campbell et al. (1963) present a range of experimental and quasi-experimental designs for research and describe the factors that affect internal and external validity and which should be accounted for. For research to have internal validity, it is required to show that the changes of the dependent variable are a result of changes in the independent variable and not due to other factors. Eight variables that can threaten internal validity are:

1. *history* which is the effect of the events occurring between measurements;
2. *maturation* is the changes that occur due to the passage of time;
3. *testing* describes the effect of administering a test on subsequent tests;
4. *instrumentation* is changes which are due to the changes in measurement tools (such as calibration) or the observers;

5. *statistical regression* is the effect on results of participants being selected on the basis of extreme scores;
6. *selection* describes the differences that result from comparison groups being selected with a bias;
7. *mortality* is the differential loss of subjects from groups being compared;
8. *interaction between these factors*.

Additionally, the novelty and Hawthorne effects can affect internal validity. These are the effects that result in performance improving when a new technology is introduced (novelty) or due to the participant being under study (Hawthorne effect) (Clark & Sugrue, 1998; Cook, 1962).

External validity describes the degree to which the results can be said to apply to cases other than the research study. For external validity, potentially confounding factors are the interactive and reactive effects of testing, selection, the arrangement of the experiment and multiple treatments. Any of these interactions or reactions may make the sample under study, or the experiment itself, not representative of the population to which it is being applied.

A robust experimental design identified in Campbell et al. (1963) which is suitable for educational research is the 'pretest-posttest control group design'. This design if implemented appropriately controls for the eight identified threats to internal validity, as well as the effect of testing on external validity (as both treatment and control group are pretested and posttested). Norman and Streiner (2003) support the use of this research design for educational studies with the caution that pretests may indicate the purpose of the intervention to participants and may therefore focus the treatment groups' learning and the control groups' motivation so biasing results.

3.3.2 Measurement of Outcomes

In looking to the future of research into laboratory activities, Hofstein and Mamlok-Naaman (2007) have identified a range of variables that such research must report on:

'- learning objectives [being targeted];
- the nature of the instructions provided by the teacher and the laboratory guide ...;
- the materials and equipment available to for use ...;
- the nature of the activities and the student-student and teacher-student interactions during the laboratory work;
- the students' and teachers' perceptions of how the students' performance is to be assessed;
- students' laboratory reports;
- the preparation, attitudes, knowledge, and behaviors of the teachers. [sic]' (Hofstein &

Mamlok-Naaman, 2007, p. 106)

This research should consider and report on each of these variables in order to ensure a valuable contribution to knowledge in the field.

As described in section 2.1.3.1, Nickerson et al. (2007) developed a framework to assess laboratory effectiveness (in the comparison of hands-on labs, remote labs and simulations) and identified influencing factors that are useful in determining potential sources of error: the individual differences in students; the real and perceived format of the laboratory; the social coordination structure and how this is implemented; the nature of the experiment and the experiment interface. Individual differences such as learning styles, gender and ability have been collected in examples of research into laboratory learning outcomes (Nickerson et al., 2007; Lindsay & Good, 2005; Barab, Dodge, & Tuzun, 2007).

Nickerson, Corter, Esche, and Chassapis's (2007) framework also identifies three measurement criteria for laboratory learning outcomes: student test scores for subjects involving laboratory activities; laboratory assignment scores; and student preferences for the different labs as measured by a questionnaire. Students' perceptions of the laboratory environment have been shown to have an effect on learning outcomes and it is reasonable to measure this outcome as well as knowledge (Hofstein & Lunetta, 2004). For this research it is practical to measure the laboratory activity scores (with pre and post intervention data being gathered) and, to a limited degree, students' preference for and perceptions of the laboratory.

On measuring learning outcomes in virtual environments Chapman and Stone (2010) conclude that methods similar to traditional learning environments transfer well to the virtual world (though they do suggest making increased use of data collected within the virtual environment).

In looking at assessment practices in the medium to high quality studies they reviewed, Bennett et al. (2007) identified that the data gathered as evidence of science understanding was mostly through written answers to 'diagnostic' questions or test items drawn from a bank of existing questions, only one had a self developed test, and another used an interview. For data gathered on evidence of attitudes to science, this was most commonly done with Likert-type questionnaires, usually developed specifically for the study. As an indication of the type of assessments to put in the questionnaire, other studies have measured ease of use, overall satisfaction with the delivery methods, instructor support and teamwork (Nickerson et al., 2007; Campbell, Bourne, Mosterman, & Brodersen, 2002).

The research reported in Corter et al. (2007) and Corter et al. (2011) comparing process and learning outcomes from remotely-operated, simulated and hands-on laboratories has similar circumstances to this research project: conducted with undergraduate students who worked in self-selected teams of 3-4 students (for this research there were 2-3 in each group) where learning outcomes were being assessed as a dependent variable. This too is useful in guiding the research design. Corter et al. (2011) used a knowledge test to measure learning outcomes, including eight questions, some of which were multiple choice. They also used a questionnaire to collect data on students' opinions' and information about their team interactions (which was another measured outcome for their study).

Tobin (1990) cautions that laboratory assessment should not be limited to 'multiple choice pencil and paper items' but should also aim to address questions such as how students can apply their knowledge, or how new content is connected to existing knowledge. This view is supported by Schunk (2012) who recommended combining multiple choice questions with other forms of assessment in line with constructivist views. Open-ended questions allow students to explain their thinking but are harder to quantify, take more time to complete and are more likely to have student's collaborate on answers within groups. Closed questions such as multiple choice options can often provide prompting information to students and are more subject to the effects of guessing, but do have support in the literature as an effective assessment tool if properly designed (Burton, 2005; McCoubrie, 2004).

Multiple choice questions are subject to guessing and copying more than open-ended questions (McCoubrie, 2004; Burton, 2005; Houston, 1976). The methods used to detect cheating are often complex statistical procedures which may include where students sit in relation to each other and what their abilities are (so affecting the probability that they would get an answer correct) (Wesolowsky, 2000; Houston, 1976; Bay, 1995). These statistics have limited applicability in this research due to the small number of questions presented to students, however Harpp and Hogan (1993) give an indication that copying is likely when a pair of students has about 20% of their exact errors in common, or that the differences in their responses is less than 10 answers out of a test of 70-90 questions. They found in their study that the students who copied were immediate neighbours. This simplified analysis will be applied in this research so that students within a group need at least 15% of their answers to be different.

Following the practices described here, this research will employ a pretest-posttest control group research design. The tests items will draw questions from existing test items where possible, and the assessment of students' attitudes will be done using Likert-type questions. The knowledge test for this research will include longer, more probing questions as well as short-answer questions.

3.3.3 Development Approach

Aside from an empirical investigation, approaches to development in research are also relevant to this research project. Ellis and Levy (2010) provide a description of design and development research and identify two essential characteristics: the process results in production of some form of ‘artifact’ and the process constitutes *research* rather than *product development* in that it addresses an identified problem, builds on existing literature and makes an original contribution to knowledge.

Ellis and Levy (2010) propose a six phase framework for design and development research:

1. *Identify the problem*. Design and development research should address a known problem. Such problems may arises from emerging situations that have no existing tool, product or model to address the problem. These type of problems often share characteristics: influencing factors (such as the system requirements or constraints) are poorly defined; the problem and possible solutions are inherently complex; there is the potential for possible solutions to change; and solutions are to some degree dependent on creativity and collaboration.
2. *Describe the objectives*. The objectives of the design and development research can usually be found in the research questions they aim to address. They always clearly relate to the identified problem and have no known or documented solution.
3. *Design and development of the artifact*. This can be based on a number of development models as suits the researcher but usually includes identifying system functionalities, analysing possible solutions, selecting a system design, then creating a prototype.
4. *Test the artifact*. This involves testing of the artifact against the identified requirements.
5. *Evaluate testing results*. The results of the testing must be analysed in terms not only of the requirements, but the artifacts validity as a solution to the problem.
6. *Communicate testing results*. Communicate the design and development process as well as the results, relating them back to the problem they are addressing and identifying the contribution the research makes to knowledge.

The literature discussed here is used as the basis for the research design in this project. The details of the research design as implemented are discussed in Chapter 6.

3.4 Research Methodology: Addressing the Research Questions

Having identified the research questions that follow from the hypothesis, these can be further categorised into four ‘phases’ for this research, each of which involves a different methodology being employed to provide answers to the questions. This is in line with research that indicates that the choice of a research methodology within engineering education research should be determined by the nature of the research question (Borrego et al., 2009).

The following phases have been identified:

1. The literature review - an investigation into learning outcomes, laboratories, models, context and virtual worlds.
2. A framework for the definition, design and application of context in this research.
3. The laboratory and virtual world integration.
4. An empirical investigation analysing laboratory outcomes under different conditions - can the null hypothesis be rejected?

Together these phases make up this research project. Each of them is outlined here, along with the justification for the methodology selected. (The four phases are addressed fully in separate chapters within this thesis.)

3.4.1 Literature Review

The following research questions have been answered (at least in part) by reviewing the current state of knowledge in the literature and by extracting and analysing the conclusions from available research:

- How does contextual information aid students in understanding the strengths and limitations of models?
- How can improvements in students’ ability to identify the strengths and limitations of models as a predictor of real-world behaviour be measured?
- Do virtual worlds provide a suitable mechanism for adding contextual information to a laboratory?

Additionally, the literature review has supplied the knowledge needed to make decisions for the following questions:

- Given the laboratory selected, what kind of contextual information should be added?
- How should the contextual information be presented?

- How can a remote laboratory be accessed through a virtual world?
- How will it be determined whether students' understanding has improved after completing the laboratory?

The extensive literature review and synthesis of the information has been presented in Chapter 2.

Outline

The research needs to be situated within the current body of knowledge. This requires an understanding of a number of topics over various fields of research. The literature review has looked at the following topics:

- the historical and current views on learning in the sciences in general and in laboratories in particular;
- the role of laboratories and their specific learning outcomes and assessment;
- types of laboratories that exist with a focus on remote laboratories;
- how models are used in education and learning;
- the nature and 'truth' of models;
- the relationship between models and laboratories;
- how context is used in learning in general and laboratories in particular;
- the relationship between context, models and laboratories;
- virtual learning environments;
- the particular affordances of virtual worlds;
- related research into specific virtual worlds and remote laboratories.

Each of these topics was addressed by searching for peer reviewed publications such as journal articles, books, conference papers and reports. The review has identified key historical and current writers in the fields, discussed the range of viewpoints to each topic, identified current thinking and provided an understanding of the state of knowledge for each topic. This information has been summarised in the literature review and been used to identify a gap in knowledge and describe the background for this research.

In this methodology the information gained from the literature review must be subjected to examination and analysed critically to draw out conclusions that answer these questions.

Further critical analysis of the literature will be covered in Chapter 7 in the discussion of the results to show how these results fit into current knowledge and where they support or deviate from this knowledge.

Justification

The investigation and critical analysis of literature that relates closely to the research topic and research results is an important part of any research report and a recognised technique for developing an understanding of the research topics and establishing the significance of results. Synthesising the knowledge gained from the literature review will contribute to answering a number of research questions and provided the background information needed to address others.

In addition, the literature review serves to situate the contribution to knowledge from the research findings into the body of knowledge.

3.4.2 Framework for Laboratory Contexts

There are a number of research questions that relate to the laboratory context that must be investigated within the research. As the core of the hypothesis is the difference in learning outcomes between 'contextualised' and 'non-contextualised' environments, justification must exist for expecting that the specific context provided may have an effect on learning outcomes. The following questions fall within this phase of the research:

- Given the laboratory selected, what kind of contextual information should be added?
- How should the contextual information be presented?
- Can general guidelines be proposed for the type of contextual information that may be presented?

The literature review provided no clear framework for answering these questions so the second phase of this research is to establish what contextual information should be used in the laboratory in order to improve the learning outcome.

Outline

Consideration of the literature on context resulted in a definition of 'domain context' that describes those elements of the real world within which the laboratory is to be interpreted and that specifically relate to the content of the lab activity. (This is described in section 2.3.1.)

The strategy that will be used to address these research questions will be to analyse the existing literature for guidelines on adding domain context to learning activities. The existing literature on the relationship between a laboratory content, context and the learning outcomes will be synthesized to gain insight into what context should be supplied and how this is best presented. While the literature has identified a number of approaches to context within laboratories, there is no description of what should constitute domain context, nor has a framework been found that can direct these decisions.

The analysis from the literature will be used to develop a new 'context framework' that provides a structure for analysing and designing context within laboratories. The framework illuminates the relationship between the domain context and the content of the laboratory. The aim is to have a framework that can be used for both analysing existing laboratories in terms of their context-content relationship, as well as a guide for designing new laboratories with context-content relationships that can be expected to improve learning outcomes.

Justification

A critical review of topical literature relevant to how context and content are related and how they can be described in laboratories, along with a review of the literature relevant to theoretical frameworks that cover this subject is the most suitable way to determine the existing knowledge in the area. Any new framework, or new application of an existing framework should be tested, and for this reason existing laboratories will be analysed using the framework to determine whether the results are sensible and useful.

3.4.3 Laboratory and Virtual World Integration

In order to test the hypothesis that contextualising a laboratory can have an effect on learning outcomes, it is necessary to have a system that allows for students to access a laboratory that either contains the contextual information or not, with all else remaining the same. For this research it was decided to use a remote lab that is accessed from within a virtual world in order to test the hypothesis. The third phase of the research, therefore, is to develop a virtual world which integrates the remote laboratory and the contextual information. The questions that relate to the platform for testing the hypothesis are:

- What experiment would be suitable to test students' ability to identify the strengths and limitations of models as a predictor of real-world behaviour?

- How can a remote laboratory be accessed through a virtual world?
- What constraints does the technical implementation of the system impose on the laboratory activity and its learning outcomes?
- What factors resulting from the technical implementation can affect the learning outcomes of the laboratory?

This phase of the research requires that a suitable approach to the development of an integrated system be selected.

Outline

The methodology used for this phase was a 'design and development' research approach (Ellis & Levy, 2010) where a prototype is conceived, designed, developed, tested and improved. Ellis and Levy (2010) describe and justify a six phase design and development approach as detailed in section 3.3.3, which will be applied in this research as follows:

1. *Identify the problem* - this is done through the development of the hypothesis and identifying the research questions to be answered.
2. *Describe the objectives* - this covers the system requirements the artifact is to meet.
3. *Design and development of the artifact* - the details of the system interfaces, functions and implementation.
4. *Test the artifact* - testing of components and their integration against system requirements.
5. *Evaluate testing results* - determining whether the requirements have been met and making changes as required.
6. *Communicate testing results* - this report communicates the results of the design and development process in section 4.1 and Chapter 5.

Justification

As a subsection of the research, the implementation of the integrated virtual world and remote laboratory system was approached according to a 'design and development' research method. This is justified as a research task (rather than product development) as it addressing an acknowledged gap, builds upon existing literature, and contributes to making an original contribution to the body of knowledge (Ellis & Levy, 2010).

3.4.4 Empirical Investigation

The research results are achieved by conducting an empirical study to test whether or not the null hypothesis described in section 3.1 can be rejected.

The questions that relate to the study, what knowledge is needed, how this affects the study design and how this will be approached are:

- How can improvements in students' ability to identify the strengths and limitations of models as a predictor of real-world behaviour be measured?
- How will the influencing factors be controlled and/or accounted for in the empirical research study and research conclusions?
- How will it be determined whether students' understanding has improved after completing the laboratory?
- Does students' understanding of models improve with the setting of the remote laboratory in a context-rich virtual world over the same laboratory in a non-contextualised world setting?
- Can future areas of research be identified?

Outline

A quantitative study is used to examine the relationship between context and a student's understanding of the strengths and limitations of models and how they apply to the real world. The relationship between these concepts (context and learning outcomes) will be analysed from collected data using appropriate statistical methods to determine whether there is a statistically significant relationship between them.

The first three phases of the research are used as inputs for this phase which is outlined below:

- *Concept definitions and study variables* are identified. The output from the phase of the research into the contextual framework is used here. Also, extraneous variables that may influence the results will be identified.
- Operational design into how to *capture and measure* those variables that will be used to test the validity of the hypothesis. The output of the development phase (the physical system) will be used as an input here, along with the design of a suitable assessment. The study should have maximum control over variables not being measured that could influence the results, or account for these within the operational design.
- *Population and sample* must be identified for the study.

- *Identification of the assumptions and limitations inherent* in the design.
- *Definition of the measurement methods* to be used.
- *Data collection process* where information on the studied variables is gathered. Criteria must be set for determining which responses should be included in the study, and which are not valid.
- *Data analysis* through organising the data collected in such a way that the research questions are answered and the hypothesis tested.
- *Interpretation* of the data analysis to determine research results including whether the results can be applied, the implications, limitations and areas for further research. (Creswell, 2013)

For meaningful results, the quantitative study should satisfy internal and external validity as far as is possible. This must be considered in the design and analysis of the empirical investigation. The literature review into research design methodologies resulted in a pretest-posttest control group research design being selected in order to address most of the threats to internal validity and some of the external threats (discussed in section 3.3.1).

The learning outcomes will be assessed by the difference in pretest and posttest scores on questions that measure student ability to identify the strengths and limitations of the model. These tests will be made of short TRUE/FALSE type questions and a number of long response questions drawn, where possible, from existing questions (see section 3.3.2). Statistical methods will be applied to the difference in pretest and posttest scores to test for statistically significant differences between the mean of the control group learning outcomes and those of the treatment group. A suitable method identified by Campbell et al. (1963) and Norman and Streiner (2003) is the use of an unpaired t test on the set of control group differences and treatment group differences.

Additional qualitative information will be gathered. This is based on the literature review findings that much of the research into laboratory learning outcomes with remote laboratories has found that students' preferences and attitudes affect the outcomes. The information will be collected using Likert-type questions which will be based on those found in the literature concerning perceptions of laboratory access modes.

Also, notes will be taken during laboratory sessions to identify any behaviours such as collaboration between groups or problems navigating the virtual world which may have an effect on learning outcomes.

Justification

A quantitative study is justified when research questions require an investigation into the differences between groups or treatments (Borrego et al., 2009). This research is looking at the differences in learning outcomes between two groups: those who conduct the laboratory with contextual information, and those who conduct the same laboratory without the contextual information.

According to Campbell et al. (1963) the pretest-posttest control group design, if properly implemented can account for the threats to internal validity posed by history, maturation, testing, instrumentation, statistical regression, selection, mortality and the interaction between these factors. It also protects against the reactive and interactive effects of testing on results.

3.5 Ethics

As this study involves human participation, ethics approval was needed. This required a clear definition of the study environment, impact on the participants, and handling of data collected. The ethical integrity of this research has been established using the University of Sydney's Human Ethics approval process (project number 2013/1078).

For this research, although all students were required to complete the laboratory activity as part of their course, participation in the research study was voluntary. Students were provided with information about the study and consent forms and could select whether or not to participate (Appendix D). The participant responses are not identifiable within this research and the laboratory activity results were not for credit.

3.6 Chapter Summary

In summary, this chapter covered the following:

- The identified gap in knowledge was restated. It is unknown whether contextualising a laboratory activity by setting a remote lab within a virtual world will help students identify the strengths and limitations of a model under study as a predictor of real-world behaviour.
- The hypothesis and null hypothesis were defined for the research:

H* - *Embedding a remote laboratory within a virtual world that presents domain context can improve students' ability to identify the strengths and limitations of theoretical models as predictors of real-world behaviours, over the ability developed using the same laboratory in a non-contextualised setting.

H_0 - Embedding a remote laboratory within a virtual world that presents domain context has no effect on students' ability to identify the strengths and limitations of theoretical models as predictors of real-world behaviours, over the ability developed using the same laboratory in a non-contextualised setting.

- The hypothesis was deconstructed to determine 15 research questions that must be addressed in order to fill the identified gap in knowledge:
    1. Do virtual worlds provide a suitable mechanism for adding contextual information to a laboratory?
    2. How can a remote laboratory be accessed through a virtual world?
    3. What experiment would be suitable to test students' ability to identify the strengths and limitations of models as a predictor of real-world behaviour?
    4. What defines domain context?
    5. How could contextual information aid students in being able to identify the strengths and limitations of models as a predictor of real-world behaviour?
    6. Can general guidelines be proposed for the type of contextual information that may be presented?
    7. Given the laboratory selected, what kind of contextual information should be added?
    8. How should the contextual information be presented?
    9. What constraints does the technical implementation of the system impose on the laboratory activity and its learning outcomes?
    10. What factors resulting from the technical implementation can affect the learning outcomes of the laboratory?
    11. How can improvements in students' ability to identify the strengths and limitations of models as a predictor of real-world behaviour be measured?
    12. How will the influencing factors be controlled and/or accounted for in the empirical research study and research conclusions?
    13. How will it be determined whether students' understanding has improved after completing the laboratory?
    14. Does students' understanding of models improve with the setting of the remote laboratory in a context-rich virtual world over the same laboratory in a non-contextualised

    world setting?
    15. Can future areas of research be identified?

- The literature provides an indication of what constitutes ‘good’ empirical research reporting and these guidelines serve as a basis for this research report.
- A number of common threats to the internal and external validity of research were identified and must be addressed within this research. A pretest-posttest control group design was identified as suitable for this research’s empirical investigation to account for most threats to internal validity and to some degree for external validity.
- Measurement of learning outcomes for laboratories was reviewed and a mixture of short questions and longer assessment items, ideally selected from a bank of questions was identified as a suitable measurement approach.
- The importance and common practice of measuring students’ attitude to laboratory activities was identified. A range of Likert-type items is most commonly used to collect this data.
- The development of the integrated remote laboratory and virtual world should be approached as a research task (rather than product development). The six step design and development research approach is suitable for this part of the research project.
- The research methodologies selected to answer these questions were:
    1. A thorough literature review to establish the background theory and to discover state of current knowledge in the fields covered by this research.
    2. A critical literature review to analyse and select or develop a contextual framework to be used in the research study.
    3. A design and development approach to the development of the integrated virtual world and remote lab.
    4. A quantitative pretest-posttest control group study to determine whether the treatment used in this research produces any statistically significant results. Also qualitative data on students perception of and attitude to the lab were collected.
- The ethics of the research is considered in terms of the research requirements and impact on participants.

Chapter 4

Creating a Laboratory Context

All learning occurs within a context, irrespective of whether that context has been actively constructed or is an incidental or unintended consequence of either the learning activity or the learner's history. The nature of the context and how this context relates to the concepts being learnt has been widely shown to have an effect on learning outcomes (Tessmer & Richey, 1997; Trigwell & Prosser, 1991; Balsam & Tomie, 2014). Whilst the effect of context has been studied in a number of disciplines and over a range of different types of learning activities, this research is specifically interested in how context can affect learning outcomes achieved in laboratory activities - an area in which there has been relatively little written.

This research has hypothesised that adding context to a laboratory activity may produce improvements in students' ability to identify the strengths and limitations of the model being investigated within the laboratory activity as a predictor of real-world behaviour. For this reason it is important to consider what contextual elements can be controlled within a laboratory activity that may have an effect on the specific learning outcome identified. The design of the context that is used to test the hypothesis is crucial to the validity of these research results, and therefore this chapter explains the process of creating the laboratory context in detail.

In order to frame the discussion, the selection of the remote laboratory used for this research is presented at the beginning of this chapter. The chapter then summarises section 2.3 of the literature review, presenting those ideas on the nature and function of context as they may relate to laboratory activities. The chapter restates the definitions of situational and domain contexts derived in the literature review and used in this research. Importantly, the lack of a suitable existing framework for describing laboratory context is identified, and this chapter presents a framework that has been developed from concepts uncovered in the literature review. This framework contributes a new approach to assessing and designing context in laboratories and can be used to analyse existing laboratories and as a guide for the design of new contextual information for labs. A case study is presented on the application of the context framework to an existing laboratory, the hydroelectric energy conversion remote laboratory. The framework is then applied to the selected inverse square law radiation laboratory chosen for this research, in order to design the contextual elements that may affect students' ability to identify the strengths and limitations of the inverse square model as a predictor of real-world behaviours.

The chapter presents the final context designed for the research experiment and concludes with the research questions that have been answered in developing, testing and applying this contextual framework.

4.1 Selecting a Remote Laboratory

The 'design and development' methodology described by Ellis and Levy (2010) has been selected to address some of the research questions that result from the hypothesis and covers the design and development of the contextualised laboratory. Step 1 of the process, namely the 'identification of the problem', has been covered by the development of the hypothesis and through the identification of the research questions (sections 3.1 and 3.2). Chapter 5 will address in detail the next steps in the process. However in order to frame the discussion on context which follows in this chapter, the selection of the remote laboratory used for this research is addressed here.

4.1.1 System Requirements for Remote Laboratory

The system requirements for the integrated remote lab and virtual world are derived and discussed in detail in Chapter 5. For this discussion, the focus is on those system requirements that will affect the choice of laboratory to use. From section 5.1, these are:

- The remote laboratory and its underlying model, must be suitable for teaching the learning objective being targeted.
- The remote laboratory can arguably be augmented by contextual information that will support the learning objective.
- The reality of the remote laboratory equipment should be established and maintained within the integrated system while students conduct the lab.

- There must be the ability for the virtual world to control the remote laboratory real equipment as well as read inputs from real equipment.
- A suitable, stable platform for the remote lab is required.
- Open source is preferred for the virtual world and remote lab platforms.
- Future work in research and use of the integrated platform should be considered.

These requirements provide the basis for the decision on which remote laboratory is most suitable for this research.

4.1.2 Selection of the Remote Radiation Laboratory

Looking at existing applications of remote laboratories in virtual worlds in the literature review, most examples use proprietary laboratories developed for use only within the virtual world and do not stand alone as remote labs, for example the Circuit Warz lab for investigating operational amplifier circuits (Callaghan et al., 2012). The development effort required excluded the possibility of developing a proprietary remote laboratory for use only with this study. Additionally, because of the sharable nature of remote labs and the hope that the results of this research can be expanded and used elsewhere, it was decided that an existing shared remote laboratory should be used for this study.

The literature review identified a number of lab sharing platforms that allow multiple institutions and users to access the same equipment in section 2.1.5. It was decided that the lab should be one that can be accessed by either the LabShare Sahara or the iLabs lab sharing platforms. These platforms are stable, widely used for a range of laboratories and they have well defined interfaces and development support.

The LabShare inclined plane and hydroelectric energy experiments and the iLabs remote radiation laboratory have been described in section 2.1.6 in the literature review as three potential remote laboratories for this research. Evaluating these in terms of the requirements has led to the selection of the remote radiation laboratory for this research as meeting all the specified requirements for the remote laboratory.

The remote radiation laboratory has the following advantages:

- *Availability*: The laboratory is up and running and available to be used. There is good technical support available from those maintaining the laboratory at UQ.
- *Available learning activity*: The laboratory has been used in the past to teach the inverse square law of radiation at a distance so teaching material and expertise is available.

- *Underlying model*: The inverse square law as it applies to radiation at a distance has a number of strengths and limitations that are not immediately obvious from executing the laboratory.
- *Inherent domain context*: The laboratory equipment itself has limited domain context.
- *Future work*: This lab is iLabs-based so an integration with the virtual world could potentially be re-used for further research and applications with other iLabs based labs.

While the inclined plane laboratory includes a model that is very well suited to this study, provides potential for further domain context to clarify the understanding of the strengths and limitations of the model, and has a large bank of assessment questions that cover the topic, it was excluded because it's availability during the entirety of the research project could not be guaranteed.

The hydroelectric energy laboratory presents a suitable model but the lab equipment itself includes much domain context and a strong narrative (section 4.4 presents a more detailed analysis of the domain context of the hydroelectric energy laboratory). For this reason it was seen as a less suitable candidate as the scope to add domain context to improve learning was more limited than for the remote radiation laboratory.

After selecting this laboratory, a suitable cohort of students was found for the study. Participants were drawn from undergraduate radiography students who were required to understand the inverse square law of radiation at a distance as part of their Health Physics and Radiation Biology course (MRTY1036) at the University of Sydney.

4.1.3 Analysis of the Inverse Square Law Model

Having selected the remote radiation laboratory, identifying how the inverse square law performs as a predictor of real-world behaviours is required for imparting, testing and evaluating students' understanding. The analysis is based on approaches to models uncovered in the literature review.

As presented in section 2.2.3, Bailer-Jones (2003) looks at a number of characteristics of models that are useful in determining what 'propositions' a model entails and whether these are true or false. False propositions do not necessarily make the model less useful (this depends on the model user's views), but understanding them and the effect they have on the representation of the model, allows identification of the limitations of the model as a predictor of real-world behaviour. Similarly, looking at the propositions that are *importantly* true (as determined by the model user) allows identification of strengths of the model.

Bailer-Jones's (2003) method of analysis was applied to the inclined plane, hydroelectric energy and radiation experiments. The analysis of the inverse square law model as used in the remote radiation laboratory for undergraduate radiography students is presented in detail here. In this case, the model user can be considered to be the academic assigning the laboratory to the students as they select the particular experiment and model in order to achieve an identified learning outcome for the students. In order to determine where the model breaks down as a predictor of real-world behaviour, the possible false and importantly true propositions it entails should be determined. Following Bailer-Jones (2003), the laboratory activity and the underlying model can be analysed for *approximations*, *idealisations* and *selectivity* used in developing the model. These are identified and assessed in light of the model users' views on the purpose of the model.

Construct Idealisation

Construct idealisation concerns whether there are relevant features of the phenomenon that have been simplified in the model in order to obtain a useful result. Not all construct idealisations result in false propositions.

For the inverse square law, the shape of the radiation source has been simplified within the model to a point source, resulting in a much simpler model than would be the case if the exact shape of the source were considered. The model is not false (the law *will* apply to theoretical point sources) but any real world application will result in data that differs from that predicted by the model. A more complicated model that accounts for the shape of the source could produce a better fit for the data, but whether this is 'better' is a judgment for the model user. In this case a more complicated model would be unsuitable mathematically for the first year radiography students and therefore, for the model user, this idealisation is appropriate.

Another construct idealisation is that the inverse square law applies to a deterministic system while radioactive decay is a stochastic process. Any radiation intensity data obtained (regardless of how controlled the experiment is) will differ from the values predicted by the model for this reason. This idealisation results in a false proposition being entailed in the model - radiation intensity at a distance is *not* deterministic.

Causal Idealisation

Causal idealisation occurs when the phenomenon being examined is different from the one which was set out to be modelled. Bailer-Jones (2003) gives the example of an experiment where factors found in the real world are controlled by experimental manipulation, such as friction being minimised in a mechanics experiment.

In the case of this research, the nature of the experiment means that the radioactive source is necessarily isolated from many, though not all, real world sources of background radiation and radiation absorbers by the safety conditions in the laboratory.

Selectivity

Models are never ‘complete’ and always involve the selection of which aspects of the real world to represent. Different models may focus on the same phenomenon but involve the selection of different aspects resulting in diverse models to describe the same phenomenon. Selective modelling can result from disregarding or even misrepresenting known aspects of a phenomenon (construct idealisation). Selective modelling means that there will be true propositions included in the model, but many more propositions not included. The significance and effect of the ignored propositions depends, once again on the model users’ views.

The inverse square model does not include background radiation, radiation absorption, the effect of magnetism on the direction radiation travels, the stochastic nature of radioactive decay or the effect of radiation exposure. This list is by no means exhaustive, there are a huge number of concepts that are related to radiation intensity at a distance from a source that exist in the real world and are not captured by the model. The model does, however, describe radiation intensity for all types of radiation (not only radioactive decay of Strontium-90 as investigated in this particular lab), and on a more general level describes different radiative phenomena (such as sound) which behave in similar ways mathematically due the spatial geometry of the phenomena.

Approximation

This is how well the model fits the data. The consequences of the idealisations and selection in developing the model and the laboratory mean that the data obtained from the experiment and any real world application of the model will not match the predictions of the model. For the model user in this case, the approximation is suitable and sufficient. The effect of the approximations can be highlighted in the experiment with repeated measurements as part of the laboratory activity.

4.1.3.1 The Strengths and Limitations of the Inverse Square Law in the Remote Radiation Laboratory

This analysis highlights only those aspects of the model that most affect how it performs as a predictor of real-world behaviour for the students in this experiment. Idealisation, approximation and selection in developing the model mean that there are many real world aspects not included in the model, however most of these will not be relevant to the model user. In summary, the strengths and limitations for the inverse square law in the remote radiation laboratory can be considered to be:

- **Strength 1 (S1)** - The inverse square law applies to many phenomena.
- **Strength 2 (S2)** - As a predictor of radiation intensity from radioactive decay, this law works as a very good predictor over aggregated data.
- **Limitation 1 (L1)** - The effect of background radiation that will be present in the 'real world' measurement of radiation intensity is not included in this model.
- **Limitation 2 (L2)** - The effect of absorption of radiation in the real world is not accounted for in this model.
- **Limitation 3 (L3)** - Radioactive decay is stochastic in nature so the inverse square law is an approximation to the radiation intensity, rather than an accurate predictor.

Having identified the remote radiation laboratory and the inverse square law as the laboratory and model for this research, the following discussion looks at the process for designing context for this laboratory in such a way as to improve students' understanding of these strengths and limitations.

4.2 Core Concepts on Context

4.2.1 Defining Domain Context

Research has shown that the environment within which learning occurs, the knowledge context of the learning activity, as well as the context in which the learning outcomes are assessed, all contribute to the cognitive processes of learning and hence to learning outcomes. While the literature broadly agrees that context is known to have an effect on learning outcomes, the reporting in the literature of what context actually means, and what elements it comprises, is diverse. As presented in section 2.3.1, this research has contributed the following definitions to differentiate between content dependent and independent contextual elements in the laboratory environment:

- *Situational context* is the environment (physical, personal, social, technological etc.) in which the laboratory is being conducted. The situational factors are independent of the specific laboratory being conducted.
- *Domain context* refers to those elements of context which are specific to the content under study. These elements relate to the specific laboratory equipment, the underlying model being investigated, the learning outcomes being targeted and the method of executing and assessing the lab activity.

This research is concerned with designing the context for the laboratory in such a way as to develop a clearer understanding of the relationships between reality, the laboratory and the model. The learning outcome that is being addressed concerns the strengths and limitations of applying the model under study to the real world. The domain context for this research can therefore be considered to be those contextual elements that relate the remote radiation lab to the real-world environment in such a way as to make the strengths and limitations of the inverse square law model clear.

4.2.2 The Relationship between a Laboratory, Model, Reality and Context

As described in section 2.2.5, the laboratory can be considered as a proxy for the complex real world. In many cases the same laboratory equipment may be used in different access modes (hands-on or remote), to investigate different models, or assess different learning outcomes depending on the laboratory activity. In each of these cases, while the situational context remains constant, the domain context will differ. It is therefore insufficient to consider only the laboratory equipment as domain context. To define the elements that make up the domain context, the relationship between the laboratory, the real world and the model under study must be considered in terms of the context in which they all exist.

Specifically, this research is using a remote radiation laboratory and virtual world to investigate the inverse square law of radiation intensity at a distance by measuring particle count emitted from a Strontium-90 source at different distances. As a targeted learning outcome it is hoped that students' understand the identified strengths and limitations described in section 4.1.3.1. Figure 2.7 in the literature review illustrated the relationship between the aspects of reality

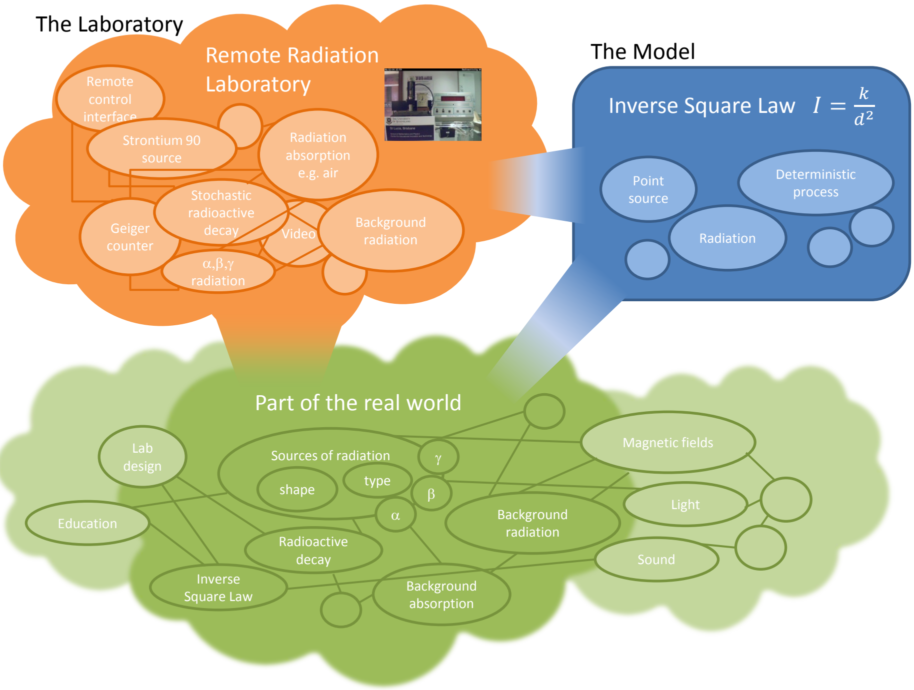


Figure 4.1: The relationship between the remote radiation laboratory, inverse square model and the real world

being investigated, the laboratory apparatus that is acting as a proxy for that reality, and the conceptual model that describes some aspect of that reality. Adapting that figure, the specific relationship between the real world, the radiation laboratory and the inverse square law model is shown in Figure 4.1.

The problem exists of how to determine exactly what contextual elements should be included in the remote radiation laboratory to provide the students with the information they need to better understand these relationships.

4.2.3 Context and Content

The design of contexts that clarify the relationships between the real world, laboratory and model (including, importantly, where the relationship breaks down) would benefit from a suitable framework for reasoning about laboratory contexts. This would support the analysis and subsequent strengthening of the contextual aspects of existing laboratories as well as the design of contexts for new laboratories that improve the learning outcomes.

Some of the research papers described in the literature review (section 2.3) provide insight into the link between context and the learning process, other research maps out how the contextual elements should relate to the concepts under study, or how students should experience the context. No single one of the researchers discussed provides a comprehensive framework that can be used to determine the specific contextual elements best suited for a laboratory, however their ideas overlap and in many cases support each other. They provide a basis for determining the key drivers that can be used in designing context for laboratory activities.

In summary, those concepts that *relate context to the content under study* are:

- Context serves either to particularise meaning or provide coherence (van Oers, 1998).
- Content can be explicitly or implicitly embodied by, embedded within or abstracted from the context (Barab et al., 2007). Embedding and embodying the content within context can be said to achieve van Oers' function of particularising meaning, while abstraction provides coherence. This is supported by Gilbert's (2006) models of context based learning.

Common to these ideas is that the content-context relationship should fulfil the functions of particularising or coherence in order to affect learning.

Considering the *type of information supplied* by contextual elements:

- Advanced organisers should provide information at a 'higher level of abstraction' than the content being studied (Ausubel, 1960).
- Comparative organisers provide information that differentiates new from existing knowledge (Ausubel & Fitzgerald, 1961).
- Cognitive bridges provide information identifying key concepts in new material and its relationship to existing knowledge (Novak, 1976).
- Information that triggers perception-induced, memory-induced or reasoning-induced context generating processes will affect learning (Kokinov, 1999).
- Context can use existing knowledge as a starting point for embedding new information (van Oers, 1998).
- Information should focus learning on the appropriate interpretation of the concept (particularisation) or relate the content to a 'larger whole' so that the knowledge is not restricted to a particular situation (coherence) (van Oers, 1998).
- Context should provide a setting, behavioural environment, specific language and relationship to existing knowledge (Gilbert, 2006).

While the description and processes involved differ, these researchers all identify the potential for contextual information to highlight new concepts to students or to help clarify the relationship between new information and existing knowledge and experiences, thereby improving learning outcomes.

Finally, considering *how context is represented*:

- Context is an internal mental representation constructed from perceived information and information that affects reasoning and memory processes (Kokinov, 1999).
- Context should be delivered within a meaningful narrative (Klassen, 2006; Gilbert, 2006).
- Context can be provided as a meaningful, experienced situation or embedded within an activity (van Oers, 1998; Gilbert, 2006).
- Context must strike a balance between level of detail and the distraction it may create (Barab et al., 2007; Chambel et al., 2004; Gilbert, 1989).

A common theme in the discussion of the representation of context is that it be presented in a narrative that 'makes sense' to students.

The following section looks specifically at applying the concepts summarised here to context within the laboratory environment and incorporates them into a framework that can guide the analysis and design of context in laboratory activities.

4.3 A Framework For Designing and Analysing Context

The objective of the framework is to develop guidelines that assist in incorporating appropriate contextual information into laboratory activities in a way that strengthens learning outcomes. This can begin either with an analysis of existing domain context in a laboratory, or the design of the context from scratch. This section begins by combining the core ideas on context (summarised in section 4.2.3) into such a framework and outlining how this can be used.

The core concepts cover three facets of context in laboratories useful in analysis and design: the *function* of the contextual elements; the *information* that the contextual element aims to deliver to students and the *representation* and integration of the contextual elements. Together with the *identification* of existing contextual elements as a starting point and a final *analysis* of results, the function, information and representation of the contextual elements these form the basis of a framework.

The framework is presented as a series of five steps but in the application of the framework it is expected that some of these will be done in parallel, with the decisions on function and

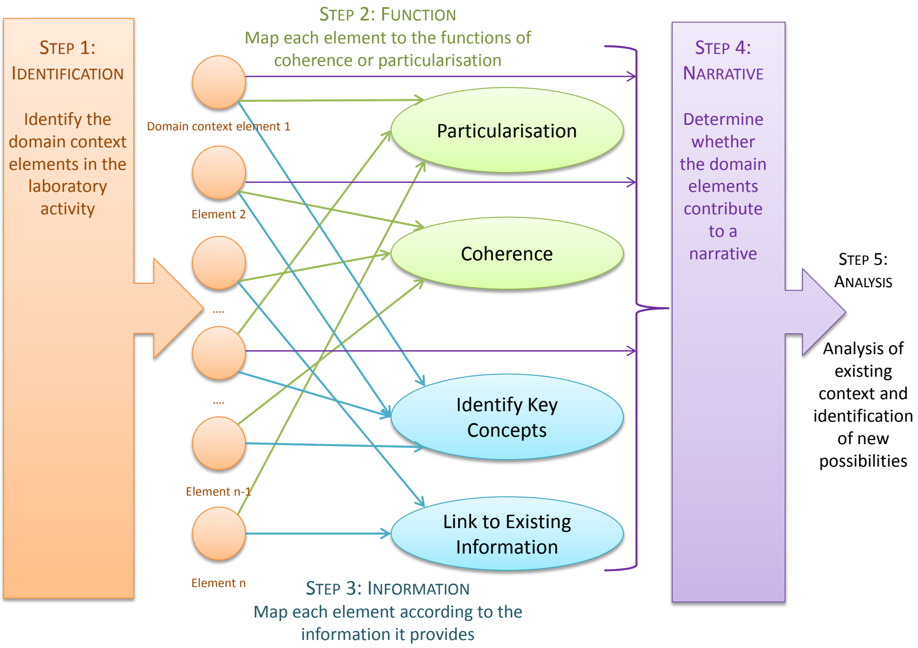


Figure 4.2: Context framework as applied to the *analysis* of an existing laboratory activity context

information being closely linked to each other and to the representation of domain elements.

Figure 4.2 represents the framework as applied to the *analysis* of an existing laboratory, while Figure 4.3 represents the framework as applied to the *design* of a new laboratory activity.

Step 1: Identification

The first step is to identify domain context elements and the desired outcomes of the laboratory.

Where the framework is used to improve existing context or design new context for a laboratory, the desired learning outcomes of the laboratory should be identified as this provides the objective for any new contextual element. For example, in this research the desired outcome is the improved ability to identify the strengths and limitations of the inverse square law of radiation intensity as a predictor of real-world behaviours. These strengths, limitations and real-world behaviours must be identified and included as the first step in applying the framework. If the targeted learning outcome was the understanding of how a Geiger counter works, the output from the first step would be different, including instead the core design and operation features of a Geiger counter.

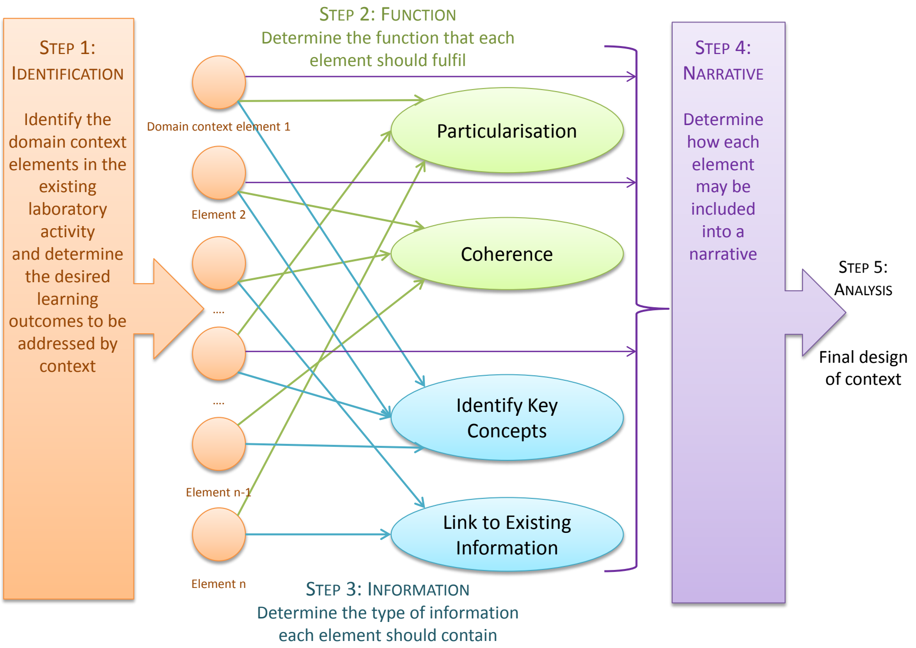


Figure 4.3: Context framework as applied to the *design* of a new laboratory activity context

In addition, where the laboratory exists it must be analysed to find the domain context elements that are already present. All laboratories provide some domain context whether intentionally designed or not. Identifying these elements requires examining the laboratory activity to find any factor or information that is not the direct subject of consideration, but is discernible to the learner and which may be expected to influence the interpretation of a concept under study and thereby influence learning. These elements may typically be found as part of the laboratory equipment, supporting documentation and instructions for the lab, or within the laboratory assessment.

Step 2: Function

The summary above shows that context is useful when it fulfils one of van Oers' functions of particularisation or provision of coherence with respect to the content being studied.

Contextual elements which may focus learning on the appropriate interpretation of the concept under study, support the function of particularisation. Those elements that serve to broaden the scope and understanding of the content to concepts outside of the particulars of laboratory activity, support coherence.

When analysing an existing laboratory, the determination of which function is fulfilled, and how well this goal is met, is subjective. This is especially apparent when the context is designed without consideration of these functions.

When designing new context, the aim of any new element of the domain context must be to meet at least one of these functions. The elements identified in the first step (from the learning objectives) should be categorised to determine which function of context may best improve understanding.

Step 3: Information

Critical to being able to fulfil the functions of context is the type of information that is delivered by each element. This information falls into two broad categories: identification of key concepts in the learning activity; and establishing a link between new concepts to be learnt and existing knowledge. The identification of key concepts will often support the function of particularisation, while linking to existing knowledge can provide coherence or particularisation depending on the specifics of the laboratory activity and the learning outcomes being targeted.

In the analysis of existing context, the identified domain context elements can be analysed to determine into which of these categories the new information falls: are the elements serving to highlight the key concepts, or are they proving links prior knowledge and experiences of the students.

When this framework is applied to the design of new domain context, the elements identified in the first step of the process, should be analysed to determine if highlighting new concepts or linking to existing knowledge will achieve the desired outcome.

For both the analysis and design, one contextual element may be interpreted in different ways by different students. The analysis of the type of information is subjective and the same goals may be met with different elements to varying degrees. What is important is that *consideration* is given to the information that students are expected to perceive and use in their learning process.

Step 4: Narrative

This step covers determining how to present the domain context.

The literature review has identified that constructing a narrative from the context may be important for enhancing the effect that context has on students' learning. While the structure of most lab activities provides a form of narrative, guiding students through the process of investigation, reasoning and drawing conclusions, this can be enhanced with domain context. Correspondingly, new domain context should be included within the laboratory activity in a sensible manner either enhancing an existing narrative or creating a new meaningful one for students to experience. This step should use the elements identified previously to determine how each element contributes to the narrative as a whole.

Applying this framework to the analysis of existing labs can identify whether the domain context provides additional information to develop a narrative formed from the lab equipment, execution and evaluation, or whether it establishes an alternative narrative within which the lab is executed. For laboratories designed without any special consideration of domain context it is likely that there will be many elements which do not explicitly contribute to such a narrative, such as diagrams in a laboratory guide. These domain context elements are part of the 'traditional' format of laboratory learning activities and do contribute to students learning by providing contextual information and embedding it within the expected form of the activity.

Similarly, when the domain context is being designed using this framework, a decision must be made on how to incorporate the domain context so that is either supports an existing lab activity narrative or provides a new narrative. According to the literature, a narrative can help focus the learning so the decision of what to select for the narrative should be made in light of the learning objectives of the laboratory. The narrative can be used as the tool to link the new information in the context elements to existing knowledge of students. Care must be taken in the design of the narrative (and the domain context elements that make it up) that the level of detail is not a distraction from the learning objectives of the laboratory itself.

Step 5: Analysis

Analysis of the domain context should aim to understand how well domain context can be expected to support student learning by assessing how well it fulfils the function, information and representation aspects of context. This framework presents a guide for analysis and design of contextual information but does not provide a quantitative measure to determine 'good' or 'bad' design of context.

For the analysis of context in existing laboratories, each step involves subjective decisions and reasoning on domain context elements. This is especially true when the framework is applied to laboratory activities whose domain context is co-incidental to the design of the lab activity and not a considered aspect of the lab design. The analysis can serve to highlight how the domain context may be changed to better meet the learning outcomes.

For the design of new domain context, the analysis step will ensure that each identified domain element has a considered place within the lab activity and has been chosen to promote student learning.

In order to further explain the use of the framework, it will be applied to the analysis of an existing laboratory activity as well as the design of the domain context for the remote radiation laboratory used in this study.

4.4 Framework Case Study: Applying the Framework to an Existing Laboratory

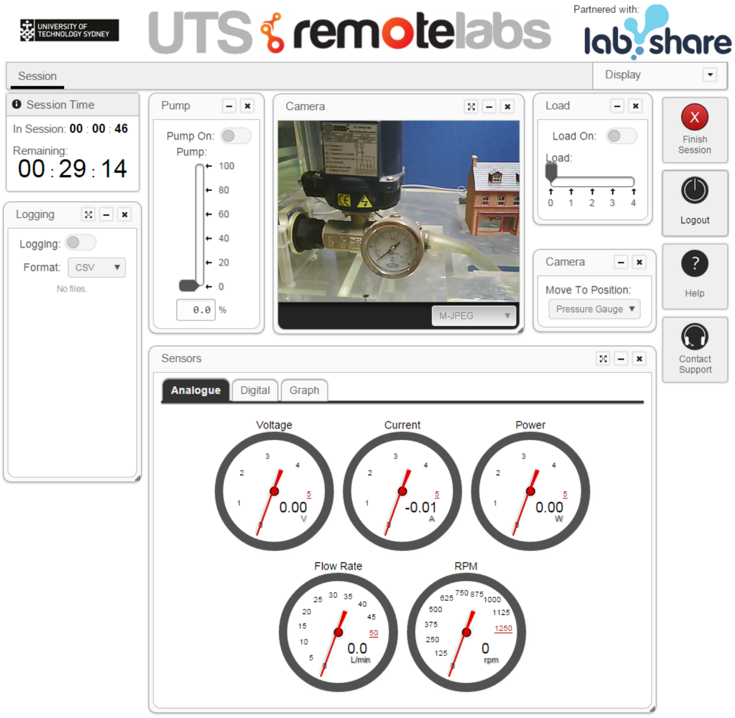
Applying the framework, analysis can be done to identify and assess the domain context of the laboratory and gather insight into whether this context is suitably presented, whether it provides suitable information, and whether it fulfils the functions of context. As a case study into analysing context within a laboratory activity, the framework is applied to the LabShare remote hydroelectric energy laboratory hosted at UTS along with the lesson plan to teach the concept of energy transformations to high school students. Details of the experiment and associated lesson plan can be found in Appendix B.

The hydroelectric energy laboratory is a remote laboratory that demonstrates the basic principle of the conversion of kinetic energy of flowing water into electrical energy, via the rotation of a turbine connected to an electromagnetic generator. (The elements and operation of the lab are described in more detail in section 2.1.6.2.) Figure 4.4 shows a screen shot of the laboratory interface.

Step 1: Identification

The concept under study is the basics of the theory of energy transformation. Domain context therefore, is those contextual elements throughout the laboratory activity that relate to the understanding of energy transformation. Probing the components of the lab activity to identify domain context elements that potentially fulfil the functions of particularising and providing coherence through identifying key concepts provides a starting point for the analysis.

When conducting the laboratory, students log on remotely to the lab and will typically have access to the following information:



In Session: 00 : 00 : 46
Remaining: 00 : 29 : 14
Logging:
Format: CSV
No files.
Pump On:
Pump: 0.0 %
Load On:
Load:
Move To Position: Pressure Gauge
Voltage 0.00 V
Current -0.01 A
Power 0.00 W
Flow Rate 0.0 L/min
RPM 0 rpm

Figure 4.4: Hydroelectric energy remote laboratory interface

- A ‘rig guide’ describing the equipment and its operation.
  This has a utilitarian description of the components of the physical laboratory equipment covering the water tanks, pumps and flow meters, the Pelton wheel, the turbine and the LED light display. The information contains reference to energy conversion such as ‘[the turbine] converts the rotational kinetic energy of the Pelton wheel into electrical energy’. All these descriptions refer to the energy conversion in the lab and make no analogies to other examples. The information provided in the rig guide (and in actuality) that may be considered domain context is the *laboratory equipment* itself.
- A laboratory lesson describing the tasks assigned and questions.
  This includes a *diagram* illustrating a number of other energy transformation cases as shown in Figure 4.5. The lesson also includes screen shots of the laboratory interface and the questions refer to the energy conversion processes indicating the learning objective of the lab to students.
- A live video stream of the real equipment where they have multiple views showing the water flowing, the real gauges and valves, and the LEDs within the model house.
  As well as the lab equipment already identified as a domain context element, the *visual of moving water, turning wheel and lit LEDs* explicitly illustrate a number of the energy

Figure 4.5: Extract from the hydroelectric energy conversion lesson

conversions in the system and can therefore be considered domain context elements. Also, the *model house* by itself provides domain context for the laboratory activity.

- The user interface which includes a simulated control panel (that allows students to manipulate the second pump and thereby change the water flow rate) and simulated gauges (which mirror the measurements of the real equipment gauges).
  These elements focus the learning on the input and outputs of the system: students control pump speed and see the result in the LEDs and the meters. The *control panel and gauges* can be considered part of the domain context.
- Any previous lectures describing the concept of energy transformation which may include specific examples, energy conversion equations, class activities etc., depending on the teacher.
  The assumption in this analysis is that students are assigned this laboratory with an introductory lesson on energy transformation that does not examine this particular example of energy transformation. This general description of energy conversion is found in the current laboratory lesson as ‘background’ information restating what students have been presented with previously. For the purpose of this case study the domain context from previous lectures and experience will be the *introduction to the basics of energy transformation as a concept*.

In summary the domain context elements identified are arguably:

- the laboratory equipment as a whole;
- the energy conversion diagram from the laboratory lesson;
- the visual of the moving water, turning wheel and lit LEDs from the live video feed;

- the model house as considered separate from the lab equipment and video feed;
- the simulated control panel and gauges;
- the introduction to the basics of energy transformation as a concept assumed in an introductory lesson before the laboratory.

Steps 2 and 3: Function and Information

Having identified the elements of domain context within this lab activity, they can be further analysed to see what new information each provides and whether these support the functions of particularisation or coherence by identifying key concepts under study or by linking to existing knowledge. In the analysis of an existing laboratory, identification of the function and information contained in the context element cannot usually be done sequentially or independently.

- *The laboratory equipment*: This presents a scaled and simplified model of real world hydroelectric power generation. The lab equipment particularises the concept of energy conversion by providing an example of its application and focusing the students' learning on an appropriate interpretation of the concept. Concerning the *information* contained, the laboratory equipment can be argued to identify the key concepts under study and link to existing knowledge. The key concepts are highlighted by the description of the lab equipment in the rig guide (which explicitly mentions energy conversion) and by the flow meter, water pressure gauges and light from the LED (which change with changing lab conditions). Students can be assumed to be aware that electrical energy is required to light the LEDs and the laboratory equipment builds on this existing knowledge and combines water pressure and flow, the turning Pelton wheel and the known electrical energy output into a single system thereby implicitly illustrating the conversion of energy.
- *The energy conversion diagram*: This diagram illustrates examples of energy conversions not found in the laboratory activity such as chemical energy in food being converted to motion of a cyclist, or electrical energy from a power outlet being converted to thermal energy in an oven. This new information both identifies key concepts by emphasising the conversion of energy and links to existing knowledge by using scenarios students are likely to be familiar with from daily life. The diagram provides coherence by linking the concept to broader applications than that of the laboratory use case alone.
- *The visual of the moving water, turning wheel and lit LEDs*: These elements taken together provide particularisation. They focus the students' learning on the motion and light in the system, both of which are forms of energy. These present information on the key concept of energy transformation implicitly. For example, the presence of LEDs imply light but

not explicitly the electrical energy generated.

- *The simulated control panel and gauges*: These domain context elements provide particularisation by focusing learning on the inputs and outputs of the system. The gauges are more explicit in the information they provide than the visual elements described above. As an example, they indicate the electrical energy output in voltage, current and power (rather than the turning on of a LED). These elements also provide new information to the student in terms of highlighting the direct relationship between pump speed and the electrical energy output.
- *The model house*: In this case the new information provided is a particular use case for electrical energy which has been transformed from energy in moving water. The model house explicitly indicates that electrical energy can be used in a home and therefore links to existing student knowledge on uses of electrical energy. This element can be argued to provide both particularisation and coherence to the learning. By using the model of a home and directly linking the concept of energy transformation to household power, the context focuses on a more specific case of energy conversion but allows students to make the link to the energy needs of a household in the real world, thereby relating the concept to a larger whole than simply the lab equipment being used.
- *The introduction to the basics of energy transformation as a concept*: This contextual information is assumed from previous information provided to students and is present in the laboratory lesson. The information implicitly describes the desired learning outcome for this laboratory and its statement within the laboratory material provides a context for the activity. As far as function goes, this provides coherence by describing the concept of energy conversion in more general terms than the use case investigated within the laboratory.

Step 4: Narrative

The remote hydroelectric energy equipment acts as a proxy for a real world hydroelectric power station, simplifying and scaling down reality so that the concept of energy transformation (and other learning outcomes) can be investigated by students. The hydroelectric power station is the ‘narrative’ for this lab activity providing meaningful application of energy conversion. The domain context elements can be analysed to determine whether they support and enhance this narrative or contribute to a different narrative experienced by students.

- *The laboratory equipment*: Of all energy conversion examples that can be investigated within a lab environment, this lab equipment has explicitly been designed to act as a proxy for a real world hydroelectric power station, thereby providing the basis for this narrative by design. All the elements of the lab equipment therefore contribute to (and are necessary for) this narrative. The laboratory equipment explicitly includes water at a height (in the first tank) and its release is shown to turn the Pelton wheel and subsequently illuminate LEDs with electrical energy generated from the turbine attached to the wheel.

- *The visual of the moving water, turning wheel and lit LEDs*: The visual display as a domain context element is a necessary element of the domain context allowing student to perceive the remote equipment. This includes both the camera feed (establishing and maintaining the reality of the equipment) and the content of the camera views (which show the movement and changes during the experiment). These elements enhance the narrative by illustrating the kinetic and electrical energy present in this system.
- *The simulated control panel and gauges*: The control panel allows students to make changes and see the effects on the gauges. Especially where it is not directly perceivable from the laboratory equipment (such as the current and voltage outputs of the turbine), the simulated gauges highlight the process the narrative describes.
- *The model house*: While the previous elements create the basic narrative the model house enhances this, extending the idea of the hydroelectric power station by associating it with household energy. The house is not part of the proxy power station but its presence potentially makes the narrative more meaningful to students by illustrating an everyday, essential aspect of power generation: it is needed for homes.
- *The energy conversion diagram and introduction to the basics of energy transformation as a concept*: These domain context elements provided as part of the lab documentation and previous lectures do not add to the narrative here.

Step 5: Analysis

The domain context comprises many elements that combine to provide a narrative that links the laboratory equipment to the concept of energy transformation by illustrating a meaningful real world use case (although simplified and scaled for lab use). The domain context fulfils the function of particularisation by clearly identifying the energy transformation concepts as they may apply in a hydroelectric power station. The learning activity links to existing knowledge of students by including the model house and further familiar examples of energy transformation thereby providing coherence and linking the specific cases of energy transformation investigated here to a larger whole.

Figure 4.6 illustrates graphically the results of the application of the framework highlighting

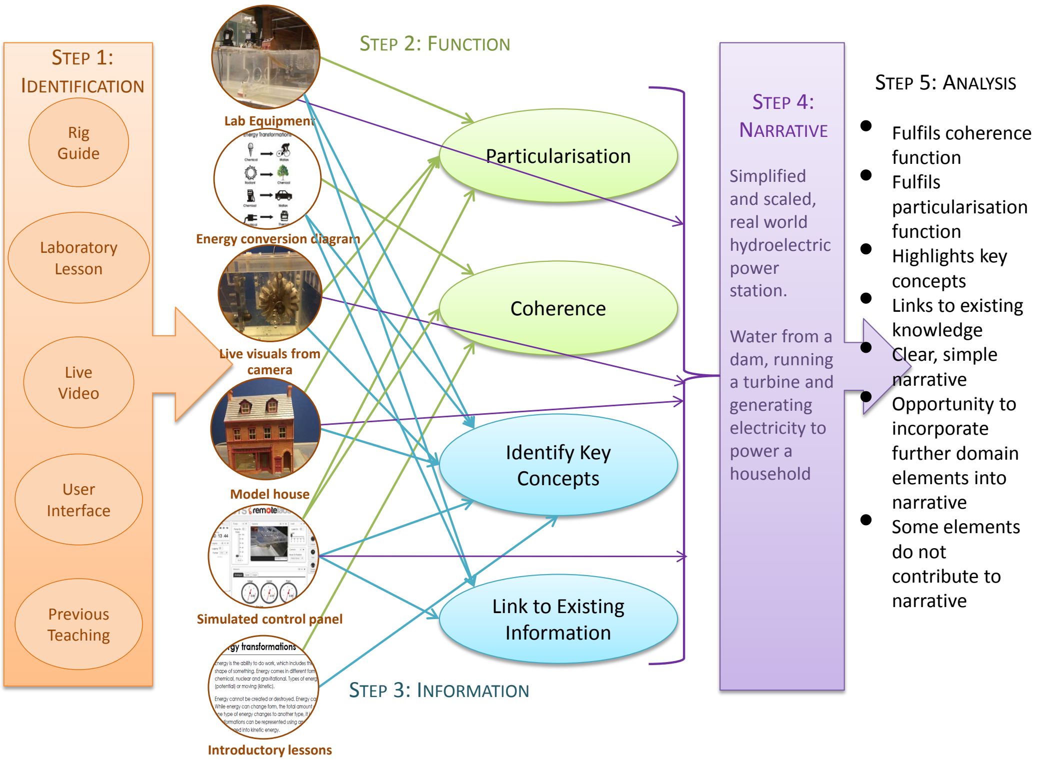


Figure 4.6: Context framework applied to the analysis of the hydroelectric energy experiment

that both particularisation and coherence are supported by the domain context elements which contain information that both links to existing knowledge and identifies the key concepts under study. The determination is that these elements all provide useful information to support the function of domain context in a learning activity.

The narrative is created by the design of the laboratory equipment and supported with the use of a number of domain context elements presented to students. However, the only contextual element which extends the narrative further than the use case illustrated by the equipment, is the model house. Additionally, there is useful domain context information which is not included in the narrative such the alternative applications of energy transformation presented in the energy conversion diagram. This provides an opportunity for improving the domain context: for instance, the model house could include solar panels which are used to power additional lights.

By applying the framework to an existing laboratory it has been shown that it is useful in determining and describing whether domain context elements support particularisation and/or coherence by linking to existing information or identifying key concepts under study. Using the framework to identify what constitutes domain context, where it exists and whether a domain context element is useful or superfluous provides insight into how domain context may be improved to potentially influence learning.

4.5 Using the Framework for the Remote Radiation Laboratory

Considering each element of the framework in turn will assist in the design of the domain context for the remote radiation laboratory investigating the inverse square law used in this research. The remote radiation laboratory is described in section 2.1.6.3. This process provides a further case study for the application of the context framework.

Step 1: Identification

In the case of applying the framework to the design of the new context for a laboratory, this step involves identifying contextual elements present in the laboratory and, importantly, the desired outcomes of the laboratory which new contextual elements should support.

Looking at existing domain context students have access to:

- The laboratory equipment (as seen on the video feed available) which consists of a Strontium-90 source and a moveable Geiger counter measuring particle count. The Strontium-90 source is not visible but the Geiger counter detector can be seen to move when running an experiment, and the particle count is displayed clearly. There is also an analogue clock which students can see moving (to emphasise the live video feed even when the Geiger counter detector is not changing).
- Previous lectures and a laboratory introduced the concept that radiation intensity varies with distance from a source. The laboratory that all students had previously completed measured light intensity at a distance from a light source. The light laboratory activity included a question about the effect of background light on the measurements.
- A laboratory guide, lesson and the user interface will be designed with new domain context in mind. They have no initial domain context.

Looking at the learning outcome targeted, the strengths and limitations of the inverse square law have been identified in 4.1.3.1 and are restated here with some possible suggestions for domain context elements that can be included to improve students' understanding:

- *S1: The inverse square law applies to other phenomena.*

  This includes forms of radiation such as light, x-rays, beta rays etc. and phenomena such as sound and gravity. This is not apparent from the laboratory equipment which investigates just the beta decay of Strontium-90, but it has been presented to students through the previous light intensity laboratory. Potential new domain elements which highlight this strength could include additional examples of phenomena which follow the inverse square law.

The phenomena to which the inverse square law applies are those where a conserved quantity is evenly radiated outward from a point source in three-dimensional space. A three-dimensional model illustrating this aspect of the model could implicitly make this connection to other radiating phenomena.

- *S2: As a predictor of radiation intensity from radioactive decay, this law works as a very good predictor over aggregated data.*

  While individual measurements will not match values predicted by the inverse square law, repeated calculations of longer durations will give a good (though not perfect) indication of radiation intensity. This strength can be well addressed through the design of the laboratory activity tasks. Domain context which emphasises that the measurements will give good, but not exact, values would be useful. A suggestion would be a simulated Geiger counter near the radiation source whose values are shown to be close to, but not exactly like, the real equipment.
- *L1: The effect of background radiation that will be present in the real world measurement of radiation intensity is not included in this model.*

  The effect of background radiation is not apparent in the lab activity where the radiation source is necessarily isolated. Examples of background radiation sources such as the sun, naturally occurring radioactive material or mobile phones could be included as domain context.
- *L2: The effect of absorption of radiation in the real world is not accounted for in the model.*

  As for background radiation, the effect of absorption would affect real world applications of the model. In some cases, such as absorption by air, this is coincidental but relevant. In other cases, such as shielding radioactive substances, the absorption of radiation is a significant factor. This weakness is implicitly suggested in the laboratory equipment by the shielding of the Strontium-90 source. New domain context elements to address this could include a shielded X-ray technician, or a radioactive waste container which is shielded.
- *L3: Radioactive decay is stochastic in nature so the inverse square law is an approximation to the radiation intensity rather than an accurate predictor.*

This is a 'construct idealisation' (see section 4.1.3.1) of the model and will affect the application of the model in the real world and the laboratory. This weakness is not apparent in the laboratory equipment. Suggestions for adding new domain context that addresses this factor could be to illustrate another random process (perhaps a roulette wheel) or emphasise the random nature of radioactivity, perhaps with a scaled model of atoms decaying.

To summarise, the process of identifying existing and potential domain context based on the desired learning outcome has resulted in a list of domain context elements that may be useful:

- the laboratory equipment itself;
- introduction to inverse square law in previous light laboratory activity and lectures;
- examples of phenomena in addition to light and radiation which follow the inverse square law;
- three-dimensional model illustrating the spatial nature of the model;
- simulated Geiger counter measurements;
- examples of background radiation sources;
- examples of radiation absorbers;
- examples of other stochastic processes;
- scaled model of atomic decay within a strontium source.

Steps 2 and 3: Function and Information

The list of existing and potential domain context elements suggests to some degree the kind of information that should be included in each element and the function it fulfils. New context must aim to emphasise the connection between the lab activity and the real world and show where the relationship works and where it breaks down. Links to existing knowledge can make use of the students' previous exposure to the light laboratory, their knowledge of electromagnetic radiation (such as mobile phone signals) or radiation shielding (such as a radiographer requiring shielding when x-raying). The key concepts are identified by drawing attention to those aspects of the laboratory activity that contribute to the real world application of the model.

- *The laboratory equipment*: This cannot be changed for this research project but the lab equipment must be visible to students from the live video feed. The user interface with its controls and output display should be clear and allow students to manipulate the experiment without unnecessary distraction. The laboratory equipment and controls particularise the activity to a specific use case of the inverse square model. Key concepts are highlighted by allowing distance and duration settings as inputs, and displaying particle count as the output.

- *The introduction to inverse square law in previous light laboratory activity and lectures*: This contextual element links the current laboratory to students' existing knowledge. As far as function goes, the previous exposure to the inverse square model provides coherence by describing the model in more general terms and in a different use case than the use case investigated within the remote radiation laboratory. This can be augmented by repeating some of the introductory material in the laboratory guide for this lab.
- *Examples of other phenomena*: This new information provides coherence, illustrating other use cases for the inverse square model. Including phenomena such as light (which students already know follows the inverse square law for intensity from previous experience) and presenting this alongside other familiar phenomena such as sound or gravity implicitly links the concepts to other phenomena and the strength that the inverse square model has in real world applications. Examples could include a light source within the virtual world dimming with distance as students navigate away from it, setting the lab at a concert where sound diminishes with distance from the stage, or setting the lab among objects obviously under the effect of gravity such as in a model of the solar system.
- *Three-dimensional model*: This domain context would highlight a key concept in the model, namely its spacial nature, and therefore hopefully contribute to coherence by assisting students to understand which other similarly radiating phenomena it applies to. Importantly this element would need to appear as three-dimensional in order to differentiate it from two dimensional diagrams of the inverse square model.
- *Simulated Geiger counter*: This domain context would contribute to the function of particularisation, applying specifically to the inverse square model for radioactive decay. The information would serve to highlight key concepts by focusing attention on potential differences in measurements that may exist in the real world. Ideally the Geiger counter would react to radiation sources and absorbers in the virtual world illustrating the effect they may have on readings.
- *Examples of background radiation sources*: This domain context would provide coherence linking the concept to real world influences not obvious from the lab environment through the use of radiation sources familiar to students (such as neon lights, computers and mobile phones, the sun, aeroplanes or a uranium mine). The reaction of the simulated Geiger counter to the presence of these background radiation source would further identify a key concept in the application of the model to the real world.
- *Examples of radiation absorbers*: Similarly to the examples of background radiation sources this would provide coherence and link to existing knowledge.

- *Examples of other stochastic processes*: This is domain context which serves to identify that radioactive decay is stochastic in nature, an aspect which is not taken into account in the application of inverse square law. This is particular to the application of the model to radioactive decay (not phenomena such as sound) and would identify a key concept in the ability of the model to predict real-world behaviour.
- *Scaled model of atomic decay*: As for the stochastic process example, this is particular to radioactivity use cases and would be useful to emphasise the key concept of the models weakness in predicting radiation intensity for this phenomenon due to the stochastic nature of radioactive decay and the fact that the source is not a point source (as the atom more closely resembles).

Step 4: Narrative

This step in the framework involves identifying a suitable narrative within which students will perceive the domain context elements. The scope for changing the narrative for this experiment is broad. As with many laboratories, the equipment itself implies a simple 'experimentation' narrative: interacting with the radiation laboratory at a distance, executing the lab lesson steps and drawing conclusions from the results.

Considering the fact that the narrative should be 'meaningful' to students and link to existing knowledge (such as previous laboratory experience), as well as the situation that some of proposed contextual elements (such as the Geiger counter and decaying atom) would have meaning in a limited number of settings, it was decided to include the domain context elements as part of a 'Research Complex'. This could extend the basic experiment narrative with students navigating through the Research Complex to do research of their own in executing the laboratory.

Alternative options considered, such as setting the laboratory within a model solar system, or at a music concert, would have provided a strong narrative and be engaging but possibly distracting. It is believed that in those scenarios, the link to the radiation experiment is too obscure and there is an increased risk that students would think the equipment was also modelled or simulated.

With the Research Complex for a narrative in mind, the domain context elements identified are scrutinised for ways in which they can be meaningfully included in the narrative.

- *The laboratory equipment*: Situating the laboratory within a virtual world changes the basic lab execution narrative, but it is important that the perception of the reality of the lab does not change when executed within the virtual world as the literature shows that this perception of reality can change learning outcomes. Research shows that video is important in establishing reality, and for this reason the new environment should retain the live video feed and laboratory controls as similar as possible to the original lab (Lindsay et al., 2009). The video serves as a method to present the laboratory equipment to students and therefore provide domain context.

- *The introduction to the inverse square law in previous light laboratory activity and lectures*: This element of domain context has already been presented to students, however as it is known that all students will begin with this prior knowledge it can be used in the new context elements. The inclusion of a *light laboratory* in the research lab can help make the link to this exiting knowledge stronger. Additionally, the introductory material can be included in the laboratory guides for students.
- *Examples of other phenomena*: Building on the idea of the Research Complex that includes the radiation experiment room and a light laboratory, further examples of phenomena that can be described with the inverse square law can be included as part of the Research Complex, such as an *acoustics room* for sounds, an *X-ray laboratory*, and a *radiation research laboratory*.
- *Simulated Geiger counter*: To present this domain element, the student's avatar could carry a simulated Geiger counter (or other particle detector such as a cloud chamber) which would react to sources and absorbers of radiation in the virtual world by changing the display, explicitly showing them as affecting radiation intensity.
- *Examples of background radiation sources*: Sources of background radiation such as sunshine and a mobile phone transmission tower can be included in the virtual world. Within the Research Complex the inclusion of mobile phones, computers and fluorescent lighting can suggest background radiation sources. These elements are implicit sources of information.
- *Examples of radiation absorbers*: The laboratories included in the Research Complex can include these absorbers in a way that makes their use obvious and sensible: the acoustics laboratory can include acoustic board walls and ceilings, the x-ray laboratory can include a shielded patient and doctor, the radiation research laboratory can be displayed as a sealed room with shielded researchers and radiation warning signs for emphasis.
- *Three-dimensional model*: This can be addressed within the light and acoustic laboratories. The light can be shown to spread and be measured in three dimensions. The common two dimensional diagram of the phenomena can be included to prompt student to make the link. More implicitly presenting the three-dimensional model, sound from the microphone in the acoustics laboratory can vary according to the inverse square law in any direction as students navigate around it.

- *Scaled model of atomic decay*: This can be an animation of atomic decay in three dimensions. This could be part of an *atomic research laboratory*. Importantly this would have to be able to be viewed in three dimensions by the student and be animated to show the stochastic (rather than predictable) nature of the atomic decay.
- *Examples of other stochastic processes*: The three-dimensional model of the atom decay will contribute to this. Another example of a stochastic process that would likely be familiar to students as such and make sense in the Research Complex could not be found.

Step 5: Analysis

Combining the results of the previous steps, the Research Complex designed will include the remote radiation lab as well as a number of other research spaces, each of which has scenarios illustrating different applications of the inverse square law. The scenarios chosen will be real world examples which are expected to be familiar to students and thereby link to the students' existing experience and knowledge. The following elements make up the design and are appended with the specific strengths and limitations they address:

- An *acoustics room* containing a microphone and speakers arranged around the microphone as well as acoustic board walls and ceiling to illustrate sound absorption, and the three-dimensional nature of the phenomenon. (S1, L2)
- A *light laboratory* showing a beam of light diffusing and spreading in three dimensions. This room also included diagrams showing the three-dimensional nature of the inverse square law. (S1)
- An *X- Ray laboratory* with shielded patient and doctor. (S1, L2)
- A *remote radiation laboratory* room containing the remote radiation laboratory controls and live video feed. This room should also include fluorescent lights and an exit sign, as well as computer and mobile equipment. (S1, L1)
- *Atomic research laboratory* allowing students to view a scaled up animated model of atomic decay. (L3)
- A *radiation research laboratory* comprising a sealed room with radiation warning signs and a suited radiation researcher. (L2)
- *Background elements* such as sunshine and a mobile phone transmission tower. (L1, L2)
- *Simulated Geiger counter* (or other particle detector such as a cloud chamber) carried by the avatar which reacts to sources and absorbers of radiation. (L1,L2)

Figure 4.7 illustrates graphically the results of the application of the framework highlighting that both particularisation and coherence are supported by the domain context elements which

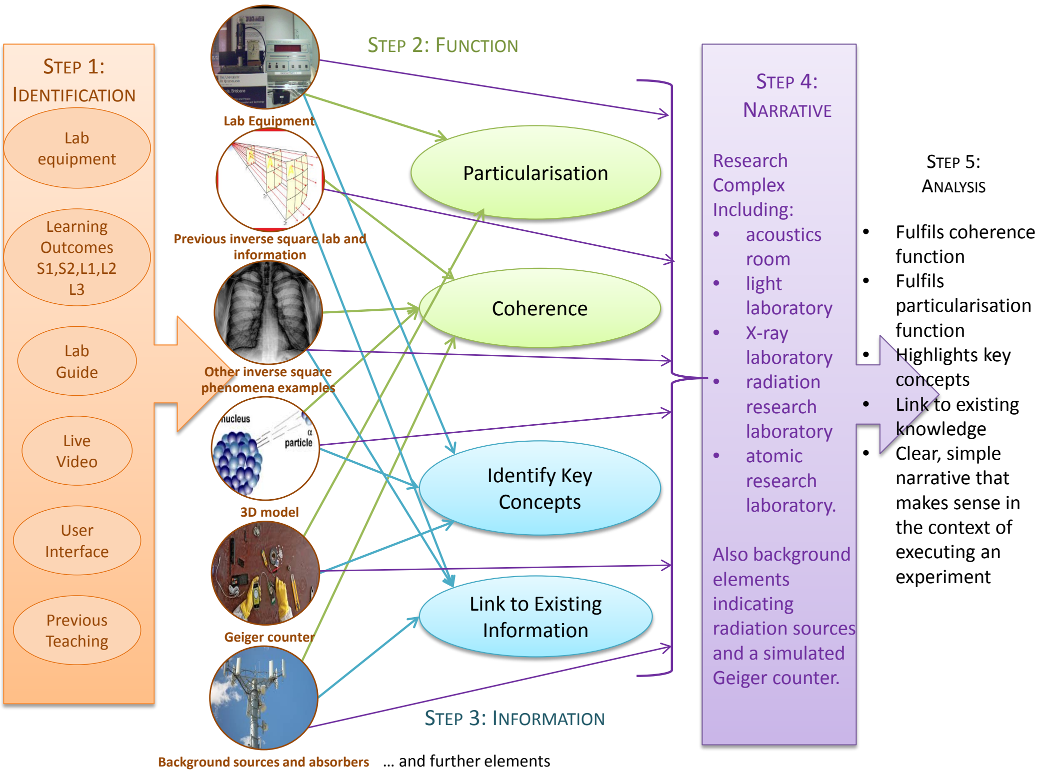


Figure 4.7: Context framework applied to the analysis of the remote radiation experiment

contain information that both links to existing knowledge and identifies the key concepts under study.

The framework as applied has resulted in the design of a contextual environment that can be expected to provide cognitive bridges for students to link the new experience to existing knowledge. By focusing on the function that is expected from each contextual element, then considering the information it should impart to students and how it is to be presented has resulted in the design of an environment that may improve the targeted learning outcomes.

4.6 Research Questions Answered

This chapter, along with background information from the literature review, has addressed a number of the research questions posed.

4.6.1 What defines domain context?

One contribution of this research has been to provide a definition of contextual elements that relate to the learning objective of the laboratory activity as opposed to those independent of the subject matter.

- *Situational context* is the environment (physical, personal, social, technological etc.) in which the laboratory is being conducted. The situational factors are independent of the specific laboratory being conducted.
- *Domain context* refers to those elements of context which are specific to the content under study. These elements relate to the specific laboratory equipment, the underlying model being investigated, the learning outcomes being targeted and the method of executing and assessing the lab activity.

This distinction has been central to the research. The definitions of context in the literature are numerous and varied. When considering context in its broadest definitions there are almost limitless factors that can affect learning (students' personal circumstances, the physical environment, the technical environment of the lab etc.). In order to target the learning outcome concerning models it was necessary to consider which elements of context are most likely to affect how students relate the model under study to the real world. Considering the laboratory as a proxy for the real world, it is the contextual elements that concern this relationship between the proxy and the reality it represents that are relevant. This led to the definition of domain context that has been applied here.

The definition provided a starting point for designing the context that could influence the targeted learning objective. As a contribution to the field, the domain context definition (which allows a focus on the content dependent elements of context) could prove very useful for clarifying further discussion and research into the design and analysis of contextualised laboratory activities. This has been addressed briefly again in section 7.1.4.

4.6.2 How could contextual information aid students in being able to identify the strengths and limitations of models as a predictor of real-world behaviour?

Context affects learning: 'it is not appropriate to discuss student learning absent from the context with which it is intertwined' (Finkelstein, 2005, p. 1206). The literature varies in its definition of context in learning, as well as in *how* context affects learning in general, but the conclusions are that contextualising learning activities can improve memory recall, knowledge transfer, student engagement and problem solving, amongst other benefits. This has been shown over a range of subjects such as languages, mathematics, engineering and medicine. However, there has been limited discussion on contextualising laboratory activities and the effects this could have on laboratory learning outcomes. In formulating the hypothesis of this research, no literature could be found on the effect that contextualising laboratories may have on how students understand the strengths and limitations of models as predictors of real-world behaviour. This research has presented an argument for why it may be expected that contextual information can improve this understanding.

Laboratories can be used to investigate models. Models, and labs themselves, are idealised or simplified representations of a very complex reality. Essential to understanding models and how they can be used in a real world, is understanding their strengths and their limitations when the knowledge is transferred and applied to real world situations. These strengths and limitations are seldom explicit within the models or laboratories.

The three way relationship between models, laboratories and reality is complex and may be opaque to learners. Domain context can act as a cognitive bridge (Novak, 1976) to link new information to existing knowledge or to focus attention on important concepts. Context is known to support the understanding of relationships between facts and to improve knowledge transfer (Gilbert, 2006). If these benefits of contextualising learning are applied to laboratory activities, they may address the recognised difficulties that students have in understanding models (such as students not being aware of the boundary between the model and reality, or having difficulty applying the model to a different context (Coll et al., 2005)). This could help improve students' understanding of the laboratory-model-reality relationship and thereby strengthen their understanding of models application to the real world. Linking the model, laboratory and the real world requires a cognitive process that, it is argued, can be helped with addition of suitably designed contextual information.

In the case of this research, the remote radiation laboratory will be contextualised with the provision of a Research Complex that includes representations of the real world that are not evident in the laboratory equipment. It is hypothesised that the domain elements will help students understand the link between the model, laboratory and the real world and thereby improve their ability to identify what the strengths and limitations of the model are when transferred from one domain (i.e. the laboratory) to another (i.e. the real world).

The results of the empirical investigation will contribute information for this research question. It is discussed in light of the results in section 7.1.5.

4.6.3 What experiment would be suitable to test students' ability to identify the strengths and limitations of models as a predictor of real-world behaviour?

In selecting the laboratory for use, a number of remote laboratories were assessed initially in terms of their availability, the level of technical support available for the study and the possibility of developing a system that could be re-used and extended in future. LabShare and iLabs based remote labs were investigated further to find a laboratory that was currently in use as a lab activity that aimed to teach an underlying model, whose strengths and limitations as predictors of real-world behaviour were not immediately apparent from the laboratory itself.

The iLabs based, UQ remote radiation laboratory was selected for this study. This laboratory met the criteria of availability for use with good technical support, the availability of lesson plans with assessment items, its underlying inverse square model presented a good basis for analysing strengths and limitations models, and there was much scope to improve the domain context available to students as the lab equipment itself has little inherent domain context. In addition, the choice of an iLabs based lab means that the integrated design may be used for future iLabs based labs.

After selecting the laboratory, a cohort of undergraduate radiography students who were required to understand the inverse square law of radiation at a distance as part of their Health Physics and Radiation Biology was found for the research. An ability to identify the strengths and limitations of the inverse square law is important for these students to be able to transfer their knowledge from the laboratory to the real world, and there is scope to improve this understanding.

This is addressed again in light of the research findings in section 7.1.3.

4.6.4 Can general guidelines be proposed for the type of contextual information that may be presented?

If the understanding of the laboratory content is to be improved by the inclusion of domain context, it is necessary to understand how the contextual information relates to the concepts under study. Analysis of the literature on context found no single description of the relationship between context and the content under study that can guide the decision about what domain context should be, but it resulted in a number of key points being identified (as summarised in section 4.2.3). These ideas cover the function, information and presentation of context. This research has concluded that, in general these facets can be combined into a framework that can provide a guideline for the design and analysis of context.

Domain context must first be identified according to what is present in the laboratory and/or the learning outcomes being targeted. The domain context should fulfil either or both of the functions of coherence and particularisation and include information that links to students' existing knowledge or identifies key learning concepts. Finally these domain context elements must be presented to students within a meaningful narrative that makes sense to them. This has been described as a five step process with guidelines on how to perform each step for either design (illustrated in Figure 4.3) or analysis (Figure 4.2) of context in a lab activity).

The hydroelectric energy lab case study presented here shows how this framework can be applied to the analysis of context in existing laboratories and indicates the adequacy of the context and identifies where there is room for improvements. The framework was also applied to the design of context for the remote radiation laboratory and has been shown to be useful as a guide to the type of contextual elements that should be included.

The framework can be considered a contribution to knowledge in the field of contextualising laboratories. Its usefulness has been supported through its application to the cases here, but should be further analysed in light of the outcomes of this research and is discussed again in section 7.1.6.

4.6.5 Given the laboratory selected, what kind of contextual information should be added?

Addressing this particular research question involved a number of steps. First, the idea of *domain context* (see section 4.2.1) defined the type of context that is relevant in this research. The contextual information added is dependent on the content of the laboratory, so in this case must be related to the remote radiation laboratory equipment, the associated lab activity tasks, the underlying inverse square law model, the learning objective concerning models, or the assessment of the lab activity. Despite investigating what aspects should make up the domain context for the laboratory, no suitable guidelines were found for designing the domain context and a new framework that combined a number of ideas in the literature was developed (as presented in section 4.3). Applying the laboratory context framework proposed in this research guided the choice of domain context from broad ideas on the targeted learning outcome to the specific elements to be included.

The decision was made to include the remote laboratory within a Research Complex that comprises an acoustics room, light laboratory, X-ray laboratory, radiation research laboratory and atomic research laboratory. The virtual world would also contain background elements indicating radiation sources and students' avatars would carry a simulated Geiger counter.

Each of these elements provided information that either highlighted key concepts or linked to students' existing knowledge to fulfil the functions of particularisation or coherence. They were combined in the form of the Research Complex in order to create a meaningful narrative for students. The process and mapping of the elements to their information and function is described in Figure 4.7.

This question is further addressed in light of the research findings in section 7.1.7.

4.6.6 How should the contextual information be presented?

The context framework allowed exploration regarding how domain context information should be presented to students, particularly that the context should form part of a meaningful narrative for the students to experience. The context should be included in the narrative in such a way that it links to a student's existing knowledge and identifies the key concepts in the content.

In this laboratory, the narrative is the student's trip through the Research Complex. Situating the remote lab in one of a number of research rooms within the Research Complex makes for a relevant setting for a laboratory activity. The design of the Research Complex is realistic in so far as it includes 'real world like' elements with which students are likely to be familiar.

The domain context is presented within a virtual world enabling the creation of rich context. Students are not required to interact with the contextual elements but it is expected that by navigating through the virtual world, they will be aware to some degree of the domain context. Setting the remote lab within the virtual world provides a suitable mechanism to ensure that students perceive the context, as opposed to providing the information in a student handout where it may not be read, and could not include three dimensional elements.

Further discussion can be found in section 7.1.8.

The results of this chapter will also contribute to other research questions which are investigated further and presented in Chapter 5. They are:

- How can a remote laboratory be accessed through a virtual world?
- What constraints does the technical implementation of the system impose on the laboratory activity and its learning outcomes?
- What factors resulting from the technical implementation can affect the learning outcomes

of the laboratory?

4.7 Chapter Summary

This chapter has covered the design of the context for the remote radiation laboratory used in this research. In summary:

- To select a suitable laboratory, the remote inclined plane, hydroelectric energy and radiation experiments were compared according to the system requirements and their underlying models. The iLabs based remote radiation laboratory at the University of Queensland was selected for this research.
- The significant findings on the design of contextual elements found in the literature have been summarised. They fall generally into conclusions about the functions of context, the type of information the context should include and the way context should be presented.
- The ideas on contextual elements, their function, information and representation have been combined into a new framework that can guide the analysis and design of context in laboratories. The new framework is a contribution to the field of context within laboratories.
- As a case study, the framework was applied to the analysis of context in an existing hydroelectric energy laboratory resulting in conclusions on how well contextual elements meet the guidelines for their function, information and representation and where improvements can be made.
- The framework was applied to the design of context for the remote radiation laboratory resulting in a specification for domain context that can support the targeted learning outcome. Application of the framework to design of the new context serves as a further case study indicating its usefulness.
- The output after applying the framework to the remote radiation laboratory was the Research Complex including an acoustics room, light laboratory, X-ray laboratory, radiation research laboratory and atomic research laboratory. Also designed were background elements indicating radiation sources and a simulated Geiger counter.

Chapter 5

Developing the Integrated Remote Laboratory and Virtual World

The literature review has looked at peer reviewed papers from researchers in virtual worlds and remote laboratories. The conclusion that has been drawn from the review is that remote laboratories are an effective and pedagogically acceptable means of presenting labs to students. While the mode of access has an effect on different learning outcomes, remote laboratories do provide a reasonable mode for testing the learning outcome regarding the understanding of models. The literature describes a number of laboratory activities set within virtual worlds (section 2.4.3.1) and illustrates their usefulness in creating a context rich environment for executing lab activities. Based on the potential that both remote labs and virtual worlds present as suitable, flexible and feasible tools for testing whether context may affect learning in labs, a virtual world based remote laboratory was selected as a testing environment for this research.

The development of the integrated remote laboratory and virtual world used to investigate the research hypothesis is addressed in this chapter. This has been done by following Ellis and Levy's (2010) six step development and design research approach selected through the literature review. This has been applied to this research as described in section 3.4.3.

Identification of the problem was done in sections 3.1 and 3.2 by defining the hypothesis and identifying the research questions to be answered. Additionally, Chapter 4 has applied the new contextual framework to guide what should constitute the domain context for this lab and the model under study. This chapter now presents further steps in developing the integrated system.

The chapter begins with the *description of the objectives of the artifact* under development.

The artifact is the integrated virtual world and remote lab system that has been augmented with domain context in order to present the contextualised laboratory to students. The objectives of the artifact are the system requirements to be met through its implementation.

The *design and development of the artifact* is presented, beginning with the justification of the selection of Open Wonderland as the most suitable virtual world environment for this research. (The choice of the remote radiation laboratory and the underlying inverse square law was justified and described in section 4.1.2). A number of possible solutions for the detailed technical design are presented, and the selection of the final design solution is justified in terms of how the requirements are met. The implementation of the remote laboratory, virtual world and context integration is presented as the final stage in this step.

The processes and results of *testing* and *evaluating* the system are then described, including explanations of the assumptions used and limitations, reliability and validity imposed by design decisions. This whole chapter serves to *communicate* the results of the design process.

Finally, research questions that have been answered through this process are presented. Conclusions are drawn on the design and development approach and the final technical implementation of the system.

5.1 Objectives of the Integrated Laboratory

The integrated virtual world and remote laboratory platform was designed primarily to be used for testing the hypothesis in this research but it is also hoped that this new system can be used for future research into improving learning outcomes in laboratories. The priority in developing the system was to meet the requirements of this research project but where possible future work was considered in design decisions.

The literature shows that while there are a range of technically feasible solutions for integrating real equipment (and specifically real lab equipment) into virtual worlds, there is no agreement on which virtual world is ‘best’ (see section 2.4.3.1). Rather, in order to select a suitable virtual world platform, it is important to look at the system requirements for what the research aims to achieve: a system that can be used to improve learning outcomes for students by adding contextual information to remote laboratories through setting them within a context rich virtual world.

The requirements for the integrated system have been based on the lessons derived from the literature review regarding students’ learning in remote laboratories and virtual worlds, the type of contextual information to be presented (as discussed in Chapter 4), the learning objective, the system technical requirements and future work in the area. These aspects are considered from technical and pedagogical standpoints and result in a list of system requirements (the objectives of the artifact). These have been described by Machet and Lowe (2012).

Suitability of the Laboratory and the Model Under Study

The purpose of this research is to improve the laboratory learning outcome concerning the understanding of models. For this reason, the selection of the model being investigated is central to the research. The model should be one which, when investigated within a lab activity, displays strengths and limitations as a predictor of real-world behaviours that are not readily discernible from the lab activity alone. This provides the opportunity to enhance students' understanding.

To determine what the strengths and limitations of the model are, the model's relationship to the real world must be explored in terms of its underlying assumptions and where these may support or diverge from real world observations, the aspects of the real world that are included in the model and those omitted, where the model succeeds or fails in achieving its purpose for the users of the model.

Not all laboratory learning activities which target the learning objective concerning models will be suitable for this research. In order to determine whether the laboratory has the potential for further contextualisation, existing context within the laboratory should be identified (all laboratory activities exist within a context).

Requirement 1: *The remote laboratory and its underlying model, must be suitable for teaching the learning objective being targeted.*

Requirement 2: *The remote laboratory can arguably be augmented by contextual information that will support the learning objective.*

Establishment and Maintenance Reality

The reality of the remote laboratory equipment must be established and maintained while students conduct the lab. Research has shown that students' perception of whether or not they are working on real equipment can affect the learning outcomes they achieve from the laboratory. The learning objective being investigated here requires students to correctly understand the relationship between the laboratory, the model and the real world (as described in section 4.2.2). It is therefore important to the learning outcome that this laboratory be understood to be real, rather than a simulation (which would not have the same relationship to either the model or reality that real equipment does). The research emphasises that maintaining the realism is of importance when incorporating remote labs into virtual worlds (Fayolle et al., 2011; Lindsay et al., 2009; Jona et al., 2011). To this end, neither the virtual world itself nor the implementation of the integration should undermine the students' perceived reality of the equipment.

It is envisaged that the perception of the reality of the equipment can be achieved and maintained to a large extent with the use of a live camera feed from the experiment as is done currently in many remote laboratory platforms. The remote lab chosen should allow for this.

Requirement 3: *The reality of the remote laboratory equipment should be established and maintained within the integrated system while students conduct the lab.*

Real Equipment Integration

In order to integrate real equipment into a virtual environment, there must be the ability for the virtual world to control real equipment as well as read inputs from real equipment. The remote laboratory must allow for this communication, control and feedback. This requirement is a necessity for integration, though the nature of the connection can be either directly from the virtual world to the hardware, or via existing remote lab interfaces (such a LabView control panel, or a lab sharing platform). Ideally this interaction should be relatively simple to implement, have been shown to work in other cases, and should not limit the functioning of the experiment in any way.

To aid in reducing the novelty effect for all students in this research, students should be able to carry out the laboratory experiment in the virtual world as they would for a conventional remote laboratory. The importance of this requirement depends on how familiar students are with real world interfaces and whether having to learn a new interface within the virtual world would distract from the learning objective.

Requirement 4: *There must be the ability for the virtual world to control the remote laboratory real equipment as well as read inputs from real equipment.*

Requirement 5: *The execution of the laboratory in the virtual world should be similar to that in the real world. This can be supported by multiple language and application sharing capabilities.*

Creation of Contextual Information

Once the laboratory is chosen and the context designed, the virtual world must be able to support the creation of suitable contextual information. It is required that objects in the virtual world can be reasonably easily created and that (if required by the context design) they have the ability to behave like real world objects. This may include simulating real world phenomenon that cannot normally be visualised (such as the field lines in the force on a dipole experiment (Scheucher et al., 2009)) or ensuring that virtual objects can imitate real ones well enough to provide contextual information.

The virtual world platform should ideally provide: a GUI tool that allows the creation of virtual world content; support for object animation; an easy method to import content of different formats; and collision detection (preferably with a physics engine).

Requirement 6: *The virtual world must be able to support the creation of suitable contextual information relevant to the chosen remote lab.*

Stable System

Most virtual worlds that are used in education (especially non-proprietary ones) use a client-server configuration where much of the constant information for the virtual world is stored on the server and users access this via a client remotely. For this research, considering the university environment within which it is to be used, the client should run cross-platform (Windows, Mac and Linux) and be able to be hosted behind a firewall for security and access issues. Installation and support of both the client and server should be clear and simple for any future development of the system.

Both the virtual world platform and the remote laboratory must be stable, available and have the same technical support available.

The remote laboratory selected should be available for use, well maintained and well documented to ensure availability throughout the research project.

Requirement 7: *A suitable, stable platform for both the virtual world and remote lab is required.*

Open Source Preferred

An open source virtual world platform is preferred. This has implications for the extensibility of the system, the cost of the installation and for future changes and development. In general, an open source platform will have lower costs and have wider acceptance within learning institutions.

For the remote laboratory too, access to the equipment and its interfaces is essential. Proprietary labs are unlikely to be suitable for this research.

Requirement 8: *Open source is preferred for the virtual world and remote lab platforms.*

Future Work in the Area

Future work would include expanding this system to allow for a number of different remote laboratories to be integrated into the virtual world. For this there are some additional requirements to be considered:

- An existing or designed *standard interface* between the virtual world and the remote laboratory would be valuable. There is some literature that describes an attempt to standardise an interface to virtual worlds such as the Virtual World and Real World Interface (Syamsuddin et al., 2009). Selecting a remote laboratory that has a widely used lab sharing platform may allow for a standard interface to at least a range of remote labs.
- *Support for multiple languages and applications*: The ability to re-use already tried and tested interfaces may aid in expanding the system for use with other laboratories. Re-use of existing components will reduce development effort and time. As remote laboratories have been developed using a number of different technologies, programming languages and platforms, the support of multiple languages and applications will allow for easier re-use and development of control interfaces and, arguably, better uptake in future work.
- *Community of developers and researchers*: Good documentation and a support community of developers and researchers interested in laboratory teaching and virtual worlds (or the integration of real equipment into virtual worlds) is useful for the project to be taken up and expanded.
- *Rapid deployment*: The ease of development for integration with new labs and for keeping up with changes to existing labs should be considered. This concerns the costs in time and money of redevelopment, the skills needed to integrate new laboratories and the limitations imposed by the virtual world.

- *Cost*: Low cost of installation and use is important in the project. Future research will depend in part on the willingness of universities and students to use and develop the system. Cost in terms of money and time for providers and users will be a factor.
- *Collaboration tools*: A significant affordance of virtual worlds, and one that may provide an opportunity to improve selected learning outcomes in laboratories, is the ability for students to collaborate while carrying out remote laboratories.
- *Virtual learning environment integration*: The ability to track and evaluate students while they conduct laboratory experiments (for instance with a virtual learning environment such as Moodle), and potentially adapt the laboratory experience accordingly in real time, is an avenue for future research.
- *Security*: Uptake of any integrated system by providers of remote laboratories (and their users) may depend on how secure the system is in terms of being able to restrict access to internal networks and authentication of users.
- *Number of users*: Once again, any system that will be useful for universities into the future must be able to support a number of concurrent users.

Requirement 9: *Future work in research and use of the integrated platform should be considered, especially future uptake by learning institutions and possible expansion to other laboratories.*

5.1.1 System Requirements

In summary, the above analysis has resulted in the following requirements list:

1. The remote laboratory and its underlying model, must be suitable for teaching the learning objective being targeted.
2. The remote laboratory can arguably be augmented by contextual information that will support the learning objective.
3. The reality of the remote laboratory equipment should be established and maintained within the integrated system while students conduct the lab.
4. There must be the ability for the virtual world to control the remote laboratory real equipment as well as read inputs from real equipment.
5. The execution of the laboratory in the virtual world should be similar to that in the real world. This can be supported by multiple language and application sharing capabilities.
6. The virtual world must be able to support the creation of suitable contextual information relevant to the chosen remote lab.

7. A suitable, stable platform for both the virtual world and remote lab is required.
8. Open source is preferred for the virtual world and remote lab platform.
9. Future work in research and use of the integrated platform should be considered, especially future uptake by learning institutions and possible expansion to other laboratories.

Given this list of broad requirements the following sections look at the options and selection of a suitable virtual world for this project.

5.2 Design and Development of the Integrated Laboratory

5.2.1 Selecting a Virtual World

A number of the system requirements identified above relate to the selection of the virtual world platform for the project. Along similar lines as selecting the remote laboratory presented in section 4.1.2, the virtual worlds are evaluated in terms of the requirements as well as discussions about the platforms in the literature (see section 2.4.4).

Focusing on the system requirements that will affect the choice of laboratory to use, Open Wonderland was considered to be the most suitable platform for this research and can be shown to largely meet the requirements:

- The reality of the remote laboratory equipment can be established with live video streaming and an ability to create content that can replicate laboratory controls if necessary.
- It has been shown that Open Wonderland can control the remote laboratory real equipment as well as read inputs from real equipment (Scheucher et al., 2009; Schmidt, 2011; Flores, 2011). Besides the existing implementations in the literature, there are further solution options.
- Open Wonderland supports multiple languages and has application sharing capabilities which provide a wider range of options for either developing new interfaces or for the re-use of existing laboratory interfaces.
- Of the three platforms considered, Open Wonderland supports the largest number of formats for importing content and makes this simple with the use of drag and drop facilities. There is no need to ‘buy’ content though this can be done if needed.
- Open Wonderland is stable with a good community of developers and support available.
- Open Wonderland is open source, as are many community developed modules which are available for re-use.
- The platform can be installed as a stand-alone, authenticated system behind a university

firewall.

While all three virtual world platforms provide feasible technical solutions for a system to support future research, Second Life was excluded due to its proprietary nature and the restrictions that would be imposed by trying to access Second Life from within a learning institution's firewalls. This meant a trade-off with Second Life's strengths of integrated learning environment support and its very extensive library of models available for purchase.

Open Wonderland and OpenSimulator are both suitable in terms of being able to be set up as stand-alone systems within a university firewall, and they are more likely to be accepted for future work due to their open source nature and support of more scripting languages than LSL (making development for them cheaper and easier). However, Open Wonderland was selected ahead of OpenSimulator due to its application sharing strengths. These include the ability to re-use already developed interfaces in a number of languages and its X11 application sharing which opens up more possibilities for re-use. Also, Open Wonderland supports document sharing for collaboration.

The limitations of this decision are that, while Open Wonderland supports a number of collaboration tools, it does not yet have an integrated learning management system as Second Life does. The available content for Open Wonderland is more limited than the models available for Second Life. Also, the physics engine for Open Wonderland is not as sophisticated as Second Life.

In support of this decision is the work by Garcia-Zubia et al. (2010) who conclude that Second Life is not recommended for integrating a remote laboratory into a virtual world.

5.2.2 Interfacing Between Virtual World and Real Equipment

The architectures of the iLabs and Open Wonderland platforms are detailed in the literature review in sections 2.1.7 and 2.4.5.

As a reference, Figure 2.5 illustrates the architecture of iLabs indicating the clients (Lab Clients) which provide the interface to the laboratory, communicating via the Service Broker to the Lab Server which deals with the operation of the hardware. UQ has developed a Java implementation for batched iLabs experiments which will be used for this research due to its cross-platform support.

The Open Wonderland architecture has been shown in Figure 2.8. Of relevance in considering the development for Open Wonderland is the tools available for developers to include content and behaviours, namely the development of cells which can have server and/or client side behaviours, scripting which can add behaviours to existing cells, the re-use of existing functional modules, and the ability to import three-dimensional models in a number of formats.

The integrated system will need to interface Open Wonderland to the iLabs Lab Server so that students who are within the Open Wonderland world can access the remote laboratory controls, see a video of the laboratory and complete the lab activity. This requires that the Lab Client and Service Broker functionality of the iLabs system must be accessible from, or implemented within Open Wonderland. This would allow users within the virtual world to be given access to the remote Lab Server and be able to control the iLabs based remote lab. Effectively, Open Wonderland should appear to the Lab Server as a generic Service Broker.

5.2.2.1 Proposed Solution

Possible solutions for this system are considered from the point of view of the level of integration of the iLabs Lab Client and Service Broker functionality into Open Wonderland. The solutions range from *wholly integrated functionality* where the Lab Client and Service Broker functionality are implemented within the virtual world (utilising Open Wonderland's scripting, cell behaviour and add-on modules), through a *partially integrated* option, to one where all iLabs functionality is *external* to Open Wonderland. These options have been investigated in Machet and Lowe (2013).

Implementing the fully external functionality would require the least development effort within Open Wonderland and provide a solution that could be re-used easily with other similar iLabs remote labs. In this scenario access to the laboratory would be through either the Open Wonderland VNC viewer module capability, or X11 application sharing, depending on the nature of the interface. Scheucher, Bailey, Gütl, and Harward's (2009) integration of an iLabs based force on a dipole laboratory into Open Wonderland provides an example of this type of integration. Their solution involved using a VNC viewer to access the Lab Client which was a LabView interface to the force on a dipole equipment. This proposition, however, would limit the ability to fully integrate the control interface with the contextual elements in the virtual world as the interface would be limited to existing available Lab Clients. Additionally, this system would be most affected by latency in external communication as every stage of gaining access to the lab and controlling it would require external communication.

With the wholly integrated functionality, the Lab Client and Service Broker functionality would sit within Open Wonderland. The Lab Client controls would be implemented in Open Wonderland, and inputs from this user interface would be used to provide information for the SOAP interface to the Lab Server. In this case, the SOAP client would need to be developed as a module for Open Wonderland as one is not currently available. Service Broker functionality, such as authentication and the storage and management of experiment data, would also need to be developed. This option allows the highest level of integration of components within the virtual world. It eliminates the need for a separate Service Broker, but also requires a large amount of development and the solution would be laboratory specific, requiring additional re-work for future lab integration.

As a compromise between a generic solution and a fully customised laboratory, the option of partially integrated functionality was selected for this research. This solution involves the development of the laboratory control interface (and other Lab Client functionality) within Open Wonderland. The Service Broker functionality would still be external to Open Wonderland using a modification of the UQ dummy Service Broker.

With partially integrated functionality, the Lab Client would not be launched from the Service Broker but rather the laboratory controls in-world would communicate with a modified Service Broker through existing Open Wonderland communication channels (for example dedicated sockets or the Open Wonderland RESTful API (Flores, 2011; Scheucher, 2010)). The Service Broker functionality would need to be modified to accept information from the Open Wonderland Lab Client.

This option requires significant development but is based on the ability to use tested Open Wonderland interfaces to external services. This option eliminates the need for a SOAP module to be developed for Open Wonderland, and makes use of existing external communication capabilities which support communication via REST. The solution will allow new labs to be implemented in Open Wonderland requiring developers only to develop a Lab Client, and it will provide the ability to re-use the new Service Broker in connections to Lab Servers. Additionally, the control interface can be designed to integrate more sensibly with contextual elements if it is designed with this in mind (rather than re-using existing interfaces).

This option provides a middle course between a more universal solution that could possibly be used with any iLabs laboratory, and a more laboratory specific solution that allows all the features of the laboratory controls to be well integrated into the Open Wonderland environment. Additionally, it is a compromise between being able to re-use existing code and redeveloping existing functionality.

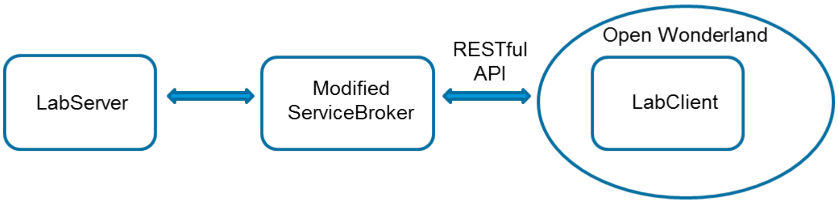


Figure 5.1: Proposed solution architecture (Machet & Lowe, 2013)

5.2.2.2 Implementation

Development for this solution is made up of three parts: The *integrated Lab Client functionality* within Open Wonderland, the interface between the Open Wonderland Lab Client and the new Service Broker (or the *ServiceBroker API*), and the development of the *modified Service Broker* as illustrated in Figure 5.1.

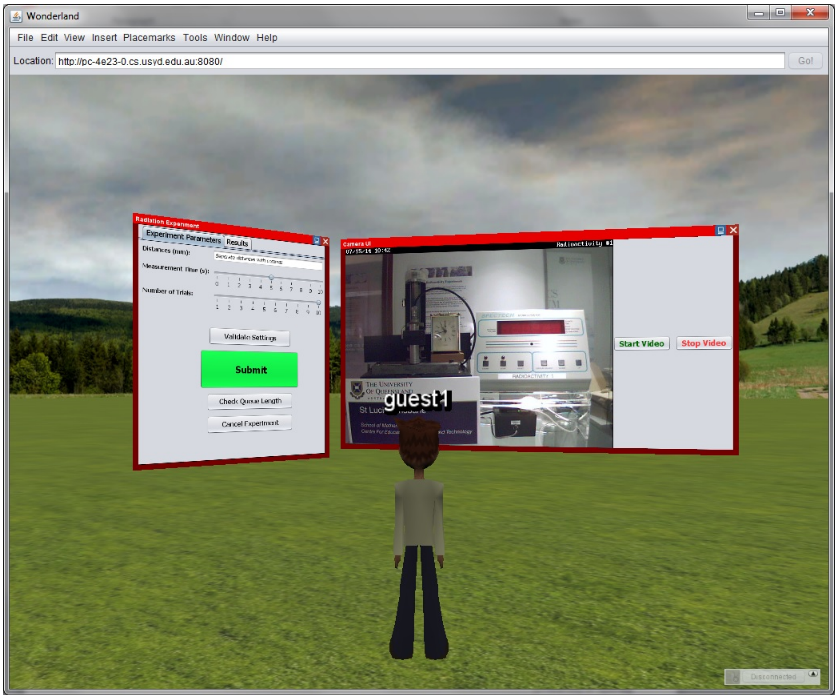
The integrated Lab Client consists of the experiment interface that the user sees when conducting the experiment. The interface controls will be developed within Open Wonderland and integrated with the contextual elements in the virtual world. The interface must include a video feed of the laboratory for establishing the reality of the equipment as in the requirements, as well as allowing students access to a fundamental contextual element - the laboratory equipment.

In terms of providing iLabs functionality, the integrated Lab Client will need to pass the correct experiment information to the Service Broker which can then interface to the Lab Server. The ServiceBroker API must provide the Lab Server with a GUID and PassKey that is known to the Lab Server in order to execute the lab. Development is required to modify a generic Service Broker to accept the new format of inputs from Open Wonderland (using a RESTful interface). The Service Broker is not required to launch the Lab Client, rather to pass the messages directly to the Lab Server.

ServiceBroker API

The ServiceBroker API contains the logic for sending and receiving the web services calls to the external Service Broker. The ServiceBroker API is the REST interface which effectively presents Open Wonderland to the Service Broker as a Lab Client. The messages to be supported by the API are described in Appendix C.

The implementation was done by modifying the existing REST module available in the Open Wonderland Module Warehouse. Each message was built in the required format, including the



Location: http://pc-4e23-0.cs.usyd.edu.au:8080/

Figure 5.2: Lab Client controls and video

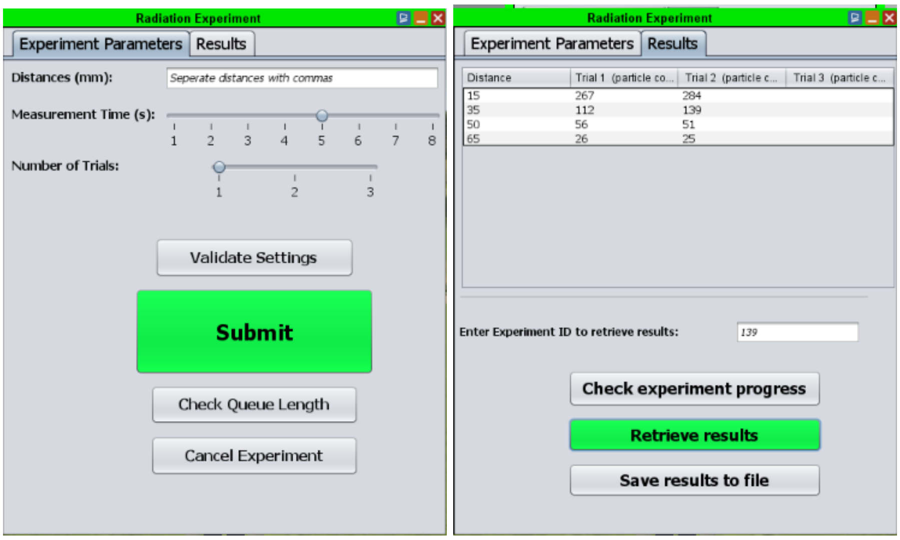
correct authentication information required by the Service Broker and Lab Equipment. Received messages are parsed to extract and validate the messages.

The ServiceBroker API functionality is not experiment specific and can be used for any iLab Service broker to interface to an iLabs experiment integrated into Open Wonderland.

Integrated Lab Client

The Lab Client consists of the experiment interface that the user sees when conducting the experiment. All development for the Lab Client functionality was done within Open Wonderland. One cell was developed for the control interface to capture user inputs and present results, and another for the video stream from the live camera. A screen shot with the controls and camera panel is shown in Figure 5.2.

The control interface cell contains the components which render the user controls and inputs for the experiment. This involved using Open Wonderland's existing Swing module to create a Swing application. The control interface consists of a tabbed interface. The first tab allows students to select the experiment parameters using graphical sliders and text fields as shown in Figure 5.3a. The second tab displays the experiment results in a table as shown in Figure 5.3b.



Distances (mm): Seperate distances with commas

Distance	Trial 1 (particle co...	Trial 2 (particle c...	Trial 3 (particle c...
15	267	284	
35	112	139	
50	56	51	
65	26	25	

Enter Experiment ID to retrieve results: 139

(a) Control panel

(b) Results panel

Figure 5.3: The integrated Lab Client laboratory controls for the remote radiation laboratory in Open Wonderland

This Swing user interface cell wraps the ServiceBroker API which allows for actions at the control panel to result in communication with the external Service Broker. Control buttons allow students to validate their experiment parameters, submit the experiment to the laboratory equipment, check on their experiment progress and retrieve their results. Feedback on errors, success and other information is provided by pop-up message windows.

Open Wonderland includes a video streaming module which supports a number of video formats. Unfortunately, the header information in the video stream from the radiation experiment specified ‘content-type=applicationoctet stream’ which results in the video module not correctly downloading or displaying the feed. The work around was to capture still images of the video feed regularly (every second) and update the video panel. The reality of the equipment could still be established as the visuals clearly show the live changes in the position of the Geiger counter and the particle count reading (as well as the background clock). Additionally it was decided that a live video feed of the equipment would be displayed on a screen visible to all students during the laboratory session.

The control panel development was experiment specific and were developed ‘in-world’ to be integrated with the contextual elements in the virtual world. Other laboratories would require redevelopment of the user control panel.

ServiceBroker

During the course of this development the developers at UQ modified their existing dummy Service Broker to support the REST interface, thereby eliminating the need for this to be done as part of this research. Their new Service Broker functionality was tested and used for the first time in this research.

Configuration

Other development tasks included the configuration of Open Wonderland, the Service Broker and the Lab Equipment. This included changes to allow the system to work behind the university firewall and maintain communication with the remote laboratory.

5.2.3 Including the Context

The application of the framework to the context design was described in section 4.5 and resulted in the design of the Research Complex that includes an acoustics room, a light laboratory, an X-ray laboratory, the remote radiation laboratory room, an atomic research laboratory, and a radiation research laboratory each designed with components that provide suitable contextual information. Also proposed were background sources of radiation and a simulated Geiger counter.

These elements were designed and constructed using models from the Google 3D Warehouse, available Open Wonderland elements (such as the microphone) and by building models with 3D modelling packages such as Blender.

Of particular note in the implementation process was the discovery that animation was not well supported in Open Wonderland. Animation had been planned for the scaled atomic decay model but the existing animation modules in the Open Wonderland Module Warehouse were no longer supported in the most recent version of Open Wonderland and discussions on the forums regarding animation during the attempted implementation revealed that there was not much current work being done in the community with integrating animations into Open Wonderland. For this reason, this contextual element could not be developed and the atomic research laboratory was excluded from the design.

The other element that could not successfully be implemented was the Geiger counter. The complexity of having a Geiger counter react to the large number of elements within the context

Figure 5.4: The Research Complex with background elements

that either emitted or absorbed radiation made development effort prohibitive. There was also a strong possibility that having implemented this feature, the delays and lags introduced by the constant, complex state changes may affect the ability for the student to navigate the world. It was decided that limiting the reaction of the Geiger counter to only certain elements could introduce further misunderstanding so it was excluded from the context.

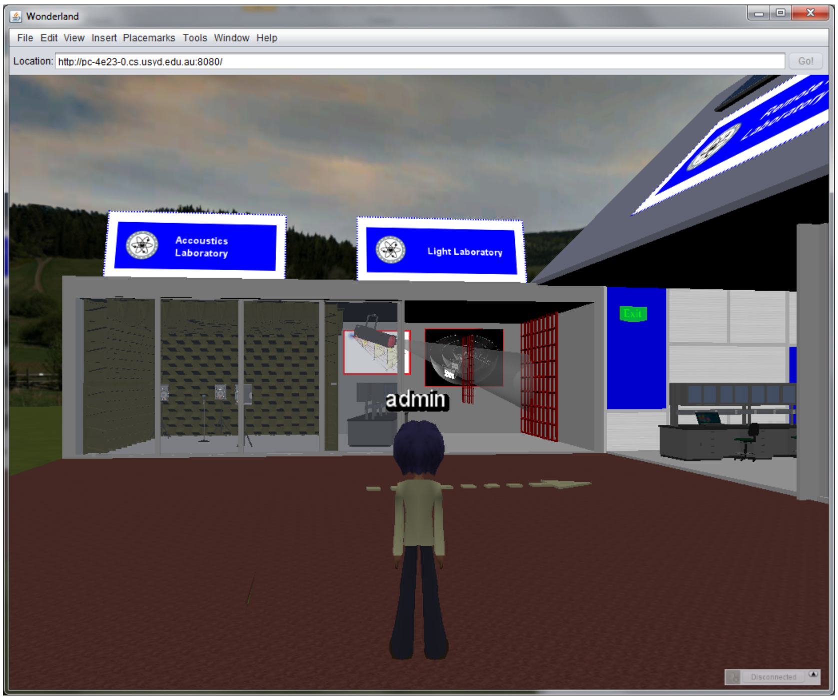
The resulting implementation is shown as a whole in Figure 5.4 and in parts in Figure 5.5.

5.3 Testing the Integrated Laboratory

In order to test the integrated system, three phases were completed.

Initially *component interface tests* were carried out. The ServiceBroker API was tested against a dummy Service Broker, and the new integrated Lab Client was tested against the Service Broker API. Additionally tests were done with the video camera feed. This testing required configuration changes and minor code changes to correct faults. The problem with the format of the camera feed was confirmed in this phase of testing and the workaround was implemented.

Secondly, *functional testing* was done with the real lab equipment against a local installation of



(a) The Acoustics Laboratory and Light Laboratory

(b) The X-Ray Laboratory and Radiation Research Laboratory

(c) The remote radiation experiment room

Figure 5.5: Parts of the Research Complex

the virtual world. The integrated system was tested against the live radiation laboratory Service Broker. The results of this testing required configuration changes on the live components to provide access to the virtual world Lab Client.

The final test was a *load test* of the system. For this test, the laboratory was set up in on multiple computers (in the actual laboratory room where the final testing was done). The virtual world was configured to have 18 'spaces', half of which contained the contextualised laboratory, the others the un-contextualised lab. The stability, latency and performance of the system was tested with all avatars accessing the virtual world and attempting to execute the lab. Most important was the confirmation that all 18 groups could simultaneously execute the laboratory from within the virtual world, and that the waiting time for the experiment to run would not exceed the time available in the laboratory session.

In this phase, it was determined that the sounds from the volume changes from the virtual world microphone were not noticeable enough to warrant the inclusion given the small change and background noise of a full laboratory room. The acoustics room was left in the Research Complex but the sound was not used.

5.4 Evaluation of Test Results

The solution proposed here involved developing Lab Client functionality within Open Wonderland (and initially requiring use of a modified external Service Broker). Additionally, the context was designed and incorporated.

The solution required a significant amount of development but made some use of existing components of the iLabs and Open Wonderland platforms. The ServiceBroker API developed is now available for re-use if new labs are included in Open Wonderland in the future. The solution did require redevelopment of a control interface for the radiation laboratory, even though multiple versions already exist (Jona et al., 2011). An advantage of the chosen solution is the ability to integrate the control interface better into the contextual elements, rather than them being limited to, for example, a VNC viewer cell. By necessity the contextual elements would need to be redesigned for each implementation.

The system was shown to be suitable and reliable in all testing. Students executing the laboratory are able to do so successfully from within the virtual world, in a similar manner to the desktop access for the remote lab. The system configuration allowed for at least 18 simultaneous sessions to execute the experiment and retrieve results within the laboratory time frame.

The main limitation resulting from the development process was the inability to include all the designed domain context. The scaled animated model of radioactive decay that was designed to address the stochastic nature of radioactive decay could not be implemented. Also beyond the development effort that could be afforded for this research project, was the simulated Geiger counter for the avatar. Additionally, the physical lab environment meant that the sound from the virtual world microphone would not be discernible as getting softer with distance.

A further limitation is that there are no assessment tasks done in-world and no integration with learning management tools. Additionally this environment was not tested for collaboration, or more than one avatar in the same virtual world space controlling the experiment. These are out of the scope of this research project but are useful for future work and to collect additional information during the lab activity.

5.5 Laboratory Description

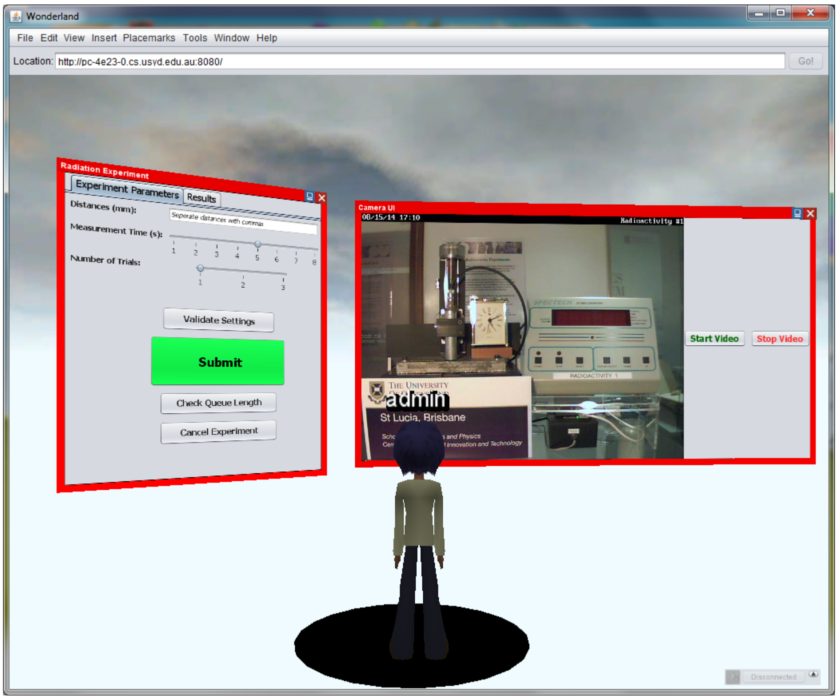
The final design of the system involved a single instance of the Open Wonderland virtual world, with 18 separate spaces. Half the spaces were empty except for the laboratory control panel and a video panel. The other half had a virtual world space with a Research Complex facility which incorporated the lab controls and video panel.

The video panel allows students to watch live changes in the equipment (as well as the live video feed displayed in the laboratory room). The control panel allows students to design and submit their experiment parameters. Students can select how many trials to run, how many measurements to take and and how long to take each measurement for. The results are available from a tab on the control panel.

Figure 5.6 illustrates the virtual world that would be visible to the control group with only the video panel and control panel in an otherwise empty virtual world.

Along with the Figures 5.4 and 5.5, Figure 5.7 illustrates what a user will see when logged into the laboratory as part of the treatment group.

The planned study will involve students completing the laboratory in groups of three (some two) within a two hour session. Each group will be presented with a guide describing how to run the laboratory equipment. All images in the laboratory guide were from the control group implementation. The ‘Running The Lab Guide’ is included in Appendix F. Additionally the researcher would present an introduction to the lab with emphasis on the real equipment in use.



Location: http://pc-4e23-0.cs.usyd.edu.au:8080/

Figure 5.6: Control group laboratory interface

Location: http://pc-4e23-0.cs.usyd.edu.au:8080/

Figure 5.7: Treatment group laboratory interface

A 'student handout' for the laboratory details the laboratory activity. The handout gives background information on the remote laboratory and on the inverse square law as an introduction. It then describes step by step instructions on how to execute the laboratory and the tasks that must be completed. The full document is included in Appendix G.

5.6 Research Questions Answered

A number of research questions have been further addressed in this chapter through the design and development of the integrated remote laboratory and virtual world system. Combined with results from the literature review, the answers are presented here.

5.6.1 Do virtual worlds provide a suitable mechanism for adding contextual information to a laboratory?

The analysis of the literature in section 2.4 has shown that virtual worlds are available as a suitable mechanism for adding context to a laboratory that is mediated by a computer interface. While the literature does not present a consensus on the pedagogic value of virtual worlds, there is agreement that the affordances of virtual worlds can be expected to contribute to learning outcomes such as increased engagement.

The literature review further concluded that virtual worlds present a number of advantages over two dimensional mediums (such as paper handouts, textbooks, or two dimensional computer interfaces) when providing contextual information for a laboratory activity. For example, virtual worlds allow for more realistic modelling of the real world and the three-dimensional nature affords the ability to develop spacial knowledge. The existing examples of laboratories in virtual worlds uncovered in the literature review highlight their immersive nature which facilitates the establishment of a narrative for the context.

The implementation described in this chapter has illustrated how, with some effort and few limitations, virtual worlds can be used to add contextual information to a laboratory. The Research Complex environment was successfully created within Open Wonderland to provide domain context to the remote radiation laboratory. Significantly, the limitations found in this implementation were the inability to provide 3D animation as context and to implement a complex real time element (the Geiger counter). These limitations are applicable to this project scope and the Open Wonderland virtual world. The selection of an alternative virtual world and more time for development may result in these limitation being overcome.

The conclusion from the literature and the experience described in this chapter is that virtual worlds do, indeed, provide a suitable mechanism for adding contextual information to laboratories in terms of technical feasibility and potential beneficial outcomes. This question is addressed again in light of the research findings in section 7.1.1.

5.6.2 How can a remote laboratory be accessed through a virtual world?

As presented the literature review in section 2.4.3.1, there are a number of options for interfacing between the real world and a virtual world that have been implemented in other projects and studies. The research covers a range of virtual worlds (most commonly Second Life, Open Wonderland, OpemSimulator and proprietary virtual worlds) as well as different real world elements (such as interaction devices, remote laboratories or real world sensors).

This research has looked at three virtual worlds and three remote laboratories and selected the platforms most suitable for this research project, namely Open Wonderland and the iLabs remote radiation laboratory. Open Wonderland was selected primarily for its open source nature, its application sharing capabilities and the ability to be used within a university network. The remote radiation laboratory, in terms of answering this research question, was suitable as the iLabs interface is well documented and supported, and the resulting implementation can potentially be used for a large range of other laboratories that use the iLabs sharing platform.

Three technical solutions were considered as solutions to the issue of interfacing the remote laboratory to the virtual world. The trade-off to be made in selecting the appropriate solution was between the development effort required, the ability to customise the laboratory interface, and the provision of a generic solution that can be re-used for future work. The decision was made to fully implement the control interface within the virtual world in order to make this as integrated as possible within the contextual information, while leaving the Service Broker external to the virtual world. This provided a solution with both reasonable development effort and a relatively high level of customisation for the control interface.

Technically, the laboratory could be executed from behind the University of Sydney, Department of Physics' firewall with no apparent lag even under the laboratory class load. The new interface developed for Open Wonderland to communicate with an iLabs Service Broker allowed for all the iLabs functionality normally available within a Lab Client to be available within the virtual world (such as checking queue length etc.). It provides a working re-usable module for Open Wonderland that could potentially be used to interface the virtual world to any iLabs batch experiment.

Identified limitations to this implementation are that collaboration and learning management tools have not been included and tested. These were not within the scope of the research project. Collaboration has been demonstrated in other Open Wonderland laboratory examples (and is well support within Open Wonderland). Other virtual worlds such as Second Life have shown successful integration of learning management systems, so that the entire laboratory from introduction to assessment can be included in the virtual world.

The conclusion that can be drawn from the literature and the experience described in this chapter is that there are a large number of feasible solutions for integrating remote laboratories into virtual worlds. The selection of solutions depends highly on the capabilities of the virtual world, the remote laboratory interface and the aims of the implementation. This chapter has illustrated how an integration can successfully achieve the aim of executing the laboratory within the virtual world using Open Wonderland and an iLabs based remote laboratory.

The question is addressed again in light of the empirical research results in 7.1.2.

5.6.3 What constraints does the technical implementation of the system impose on the laboratory activity and its learning outcomes?

Most of the compromises and design decisions made throughout the development of the combined virtual world and remote laboratory were deemed not to constrain the laboratory activity or learning outcomes but rather to affect the development effort and future uptake of the system. Some of these decisions were:

- Selection of Open Wonderland and iLabs as platforms. The result of selecting a widely used laboratory access system and a freely available open-source virtual world platform is to allow for simple, cost effective integration solution available for a wide range of laboratories for future work and research.
- Re-use of existing components of the iLabs and Open Wonderland platforms such as the available Open Wonderland external communication module to reduce some development effort. This assisted in the development in this project and, once again, can be re-used for future developments due to the modular nature of Open Wonderland.
- A significant amount of development effort for implementing a laboratory interface within the virtual world (an iLabs Lab Client equivalent). Any future lab integration into this system would need its own laboratory interface to be redeveloped which is a consideration for future implementations.

The main limitation resulting from the development process was the inability to include all the designed domain context. The limitations were:

- *Animated atomic decay contextual element*: One weakness of the inverse square model as it applies in this lab, is that the process of atomic decay is stochastic and so the values predicted by the model are approximations only. The scale of atomic decay makes the stochastic nature impossible to see in the laboratory although its effects are seen in the measurements taken. To address this weakness it was planned to have an animated, scaled-up model of an atom decaying as part of the Research Complex environment. While initial investigations suggested that Open Wonderland could support the import of animations created with other tools (such as Alice, Blender etc.), this was found impossible to satisfactorily implement with the latest version of Open Wonderland and the external packages.
- *Simulated Geiger counter*: To emphasise the effect of additional sources of radiation and radiation absorbers in the environment (a weakness of the model as a predictor of radiation intensity in the real world) it was planned that the avatar carry a Geiger counter (or similar) that could react to the radiation sources and absorbers in the environment. When developing the technical design for this element, it was found that the complexity of having a Geiger counter react to the large number of elements within the context that either emitted or absorbed radiation made development effort prohibitive and the effects of the high processing requirements and world updates on the movement of the avatar could not be confirmed.
- *Microphone sound*: As an example of a phenomenon that follows the inverse square law of intensity at a distance, an acoustics room was included in the Research Complex. Initially it was planned that students be able to hear the sound from the microphone and 'experience' the reduction in volume as the navigated further from the microphone. During testing however, it was found that the differences in the volume of the sound were barely noticable in the laboratory room and it was believed they would not be able to be discerned when the lab room was filled with students.

The effect of these limitations was that the three-dimensional affordance of the virtual world was not used to its full potential, possibly affecting the engagement of students with the context, and weakening the narrative provided by the contextual elements in the virtual world. The implication of the limitations on the results of the research are discussed further in section 7.1.9.

5.6.4 What factors resulting from the technical implementation can affect the learning outcomes of the laboratory?

This research looked into the literature concerning students' learning in remote laboratories and in virtual world environments (discussed in sections 2.1.5 and 2.4.2 respectively) and identified a number of factors that have the ability to affect learning outcomes. Some of these factors needed to be considered when developing the integrated testing system to ensure validity of research results. These factors were included in the requirements for the integrated system described in section 5.1.

The ability to create context in a virtual world was one of the system requirements for the integrated virtual world and remote laboratory platform, and the requirement that was most likely to have an impact on the learning outcomes. The domain context in this research is the independent variable being manipulated to determine the effect on a specific learning outcome. The ability to create this domain context is critical to being able to investigate the hypothesis, and was an important factor in selecting Open Wonderland as a virtual world platform. As in the discussion above (section 5.6.3), the creation of the context was subject to some limitations in the technical implementation but the final integrated system was able to present the control and treatment groups with laboratories that had significantly different domain context.

A significant influencing factor found in the literature was preserving the perception that students have of the reality of the remote laboratory equipment. Establishing and maintaining the perception of the reality of the laboratory equipment is important when considering the effect that laboratory access modes have on learning outcomes as students have been shown to respond differently to remote laboratories and simulations (where there is no real equipment). In order to establish and maintain the perception of the reality of the laboratory equipment it was decided to keep the video panel similar to the remote laboratory on its own. This was done for both the treatment and control groups with the aim of ensuring that any changes to learning outcomes from the labs would not be attributable to the changes in the perception of the reality of the lab. This has been described in section 5.1. In the final implementation, while the video could not be streamed to the virtual world, a work around allowed for a snapshot that updated every second. Students could view the changing clock and particle count while they were conducting their experiment. In order to minimise the influence of the unfamiliar nature of the world and ensure that all students understood that the equipment was real, both laboratory sessions began with an introduction that explained the remote nature of the equipment and showed the video feed with live views of the UQ lab. The explanation stepped students through the laboratory controls, explaining the steps and each group of students was provided with a laboratory guide which included these instructions.

Looking at the validity requirements, the novelty effect of the implementation must be considered in analysing the results. The design of the study and the technical implementation kept the control and treatment groups as similar as possible in terms of the novelty of the environment, primarily by setting the control groups' laboratory within the virtual world (albeit an empty one). Both the remote laboratory and virtual world as a laboratory environment were new to all the students as a mode of laboratory in this course.

Another influencing factor is how distracting the virtual world may be to students in terms of taking their attention away from the learning activity. While it can be expected that the novelty of the virtual world will increase students engagement in the laboratory activity, it is important that navigating through the virtual world does not provide a barrier to completing the laboratory activity, nor that the contextual elements distract or confuse students. The virtual world environment and its contextual elements must be engaging and not distracting to students.

Each of these questions will be addressed again in terms of the research result and the discussion presented in section 7.1.10.

5.7 Chapter Summary

This chapter has detailed the process and the results of the 'design and development' research approach that was taken to address a number of the research questions that emerged from the hypothesis. In summary:

- The system requirements for the integrated virtual world and remote laboratory were defined as:
    1. The remote laboratory and its underlying model, must be suitable for teaching the learning objective being targeted.
    2. The remote laboratory can arguably be augmented by contextual information that will support the learning objective.
    3. The reality of the remote laboratory equipment should be established and maintained within the integrated system while students conduct the lab.
    4. There must be the ability for the virtual world to control the remote laboratory real equipment as well as read inputs from real equipment.
    5. The execution of the laboratory in the virtual world should be similar to that in the real world. This can be supported by multiple language and application and

application sharing capabilities.

   6. The virtual world must be able to support the creation of suitable contextual information relevant to the chosen remote lab.
   7. A suitable, stable platform for both the virtual world and remote lab is required.
   8. Open source is preferred for the virtual world and remote lab platforms.
   9. Future work in research and use of the integrated platform should be considered.

- To select a suitable virtual world, the Open Wonderland, Second Life and OpenSimulator platforms were compared according to these requirements. Open Wonderland was selected for this research.
- Possible solutions to integrating an iLabs base remote lab into Open Wonderland were presented as a fully integrated, partially integrated or fully external solution depending on the level to which iLabs Lab Client and Service Broker functionality were included in Open Wonderland. The partially integrated solution was selected as providing the best trade-off between a re-usable solution with minimal development and a customised solution allowing for sensible integration of the control interface.
- The technical implementation of the system was described in terms of its components: the ServiceBroker API; Integrated Lab Client; the modified Service Broker; and configuration of the system.
- The integration of the previously designed domain context Research Complex was described. All components of the designed context could be implemented except the simulated Geiger counter and model of atomic decay.
- The integrated system was successfully tested and confirmed as providing the required functionality under the expected load. Testing resulted in eliminating the sound variations in the acoustics room as they would not be noticeable in a noisy laboratory room.
- The results from the design and development research approach process suggest that the development was successful.

This chapter has shown that a remote laboratory can be integrated into a virtual world and contributed to the body of knowledge by presenting a solution that is re-useable for other iLabs based labs to be included in Open Wonderland. The solution highlighted some limitations to such an implementation.

Chapter 6

Empirical Investigation

Following the methodology described in Chapter 3, the previous chapters have described the selection, design and development of the test system with its included remote radiation laboratory and Research Complex context that will be used for the empirical investigation. This chapter will detail the design of the empirical investigation that is used in this research to answer a number of the research questions, primarily to determine whether the null hypothesis (presented in section 3.1) can be rejected.

This chapter covers the selection of the research design, and then follows the research design process describing the definition of the study variables, the selection of the population and samples used, providing a description of how the variables will be measured and captured, the approach taken to data analysis and all the known assumptions and limitations of the empirical study. The validity of the research results is considered in light of the specifics of the research design. This chapter also includes the description of the data collected, and a summary of this data.

The statistical analysis of the data and the results of this treatment are presented in this chapter. The interpretation of the results is left for the next chapter where the implications of the research results are discussed further.

6.1 Empirical Investigation Design

6.1.1 Research Design Selection

A hypothesis for this research has been developed from the identification of a gap in knowledge. The testable null hypothesis will be investigated through the use of a quantitative study presented in this thesis. The hypothesis, H, and the null hypothesis, H_0, are given again here for reference:

> H - *Embedding a remote laboratory within a virtual world that presents domain context can improve students' ability to identify the strengths and limitations of theoretical models as predictors of real-world behaviours, over the ability developed using the same laboratory in a non-contextualised setting.*
>
> H_0 - *Embedding a remote laboratory within a virtual world that presents domain context has no effect on students' ability to identify the strengths and limitations of theoretical models as predictors of real-world behaviours, over the ability developed using the same laboratory in a non-contextualised setting.*

As the hypothesis implies, the study must investigate the same learning outcomes under two different conditions and compare them. The *treatment group* subjects will complete the laboratory under the condition of a contextualised laboratory, while the *control group* subjects' condition is a non-contextualised setting for the laboratory activity.

A pretest-posttest control group design was selected for this empirical investigation. This involves the random assignment of two subsets of a sample population to either a control or treatment group. Each group is administered a pretest, then subjected to the treatment or control environment, and subsequently required to complete a posttest. This form of research design has been shown to be suitable for educational research (Campbell et al., 1963; Norman & Streiner, 2003), accounting for many of the common threats to internal validity through the randomised assignment of subjects, the inclusion of a control group and the use of measured differences between pretest and posttest scores (this has been discussed in more detail in sections 3.3.1 and 3.4.4).

In addition to this research design approach, qualitative data was collected and observation used to provide further insight into students' perceptions of their experience within the laboratory.

In accordance with good practice identified in the literature review, this empirical investigation has looked to meet the criteria suggested by Bennett et al. (2007) for high quality research:

to report on the reliability and validity of the data collection methods and analysis methods; to account for and eliminate potential sources of error or bias that may result in alternative explanations for the findings; ensure the sample size is sufficient; match the control and experimental groups; collected data before and after interventions; have attitude or (as in this case) understanding as an explicit independent variable; apply appropriate assessment measures and eliminate researcher bias; report on as wide a range of measured outcomes as possible; and attempt to make the research situation as representative of a normal learning environment as possible.

6.1.2 Concept Definitions and Study Variables

The concepts involved in this hypothesis have been defined within the literature review and expanded in the discussion on context and the laboratory in previous chapters. Looking at them from the point of view of the empirical study, the concepts that provide the measurable study variables are defined here.

Independent Variable: Domain Context

Domain context comprises the content-specific components of the context of the laboratory as has been defined in section 4.2.1. The domain context was designed with the aid of the newly defined context framework, and the resulting Research Complex and surroundings that make up the context are described in section 4.5.

The context is the *qualitative, independent, nominal* variable which differentiates the treatment group from the control group. Screen shots of the different interfaces that are presented to the control and treatment groups have been illustrated in section 5.5.

Dependent Variable: Learning Outcomes

The learning outcome described as a student's ‘ability to identify the strengths and limitations of theoretical models as predictors of real-world behaviours’ has been identified in the literature review as a widely accepted laboratory learning outcome, and one that can arguably be affected by the context included in the laboratory activity. This learning outcome is the *dependent* variable.

6.1.3 Other variables

It is apparent from the literature review that an important aspect in laboratory learning outcomes is students' perceptions of and attitudes to laboratory activities (Lindsay & Good, 2005; Corter et al., 2007; Nickerson et al., 2007). For this reason, a qualitative measurement was done of student attitudes to the lab in terms of how they rated the experience of the remote laboratory and virtual world environment. This information was not intended to be used in testing the null hypothesis, but rather to collect information that may be useful in giving an indication of the influence of confounding factors such as the novelty effect of the new technology, or possible learning preferences of students.

Additionally, informal observation of the participants was done to determine whether any groups had particular difficulty with conducting the laboratory activity.

6.1.4 Population and Sample Selection

The *population* for this research is university students in the sciences who are taught about models through the use of laboratory activities. A subset of this population is those students learning about the inverse square model through a laboratory activity.

The *sample* for this research was a cohort of students completing the Health Physics and Radiation Biology course (MRTY1036) in the second semester of 2014 at the University of Sydney (University of Sydney, 2014, 'Health Physics and Radiation Biology (MRTY1036)'). These are undergraduate radiography students who are required to develop an understanding of concepts in radioactivity including how radiation varies at a distance from the source. As part of this course the students currently investigate the inverse square law with a laboratory measuring light intensity at a distance, and the understanding of the strengths and limitations of the model is an identified outcome for their lab activities. All students came into the course with relatively high entrance requirements but no required physics at high school level (J. O'Byrne, personal correspondence, August 2014).

The 2014 cohort of students included 97 students. All their laboratory work was done in groups of three (some in twos) which were self-selected on the day of the laboratory. While each group completes the laboratory activity together, each student is required to submit their own responses to the laboratory assessment. Completion of laboratory activities is a course requirement but for this laboratory activity the results did not count towards their course scores (the students were not aware of this).

6.1.5 Identification of Assumptions and Limitations

In designing this research study there are a number of assumptions that have been made, and limitations imposed by the selection of the research design.

The laboratory time allocation and the structure of the MRTY1036 course required students to conduct the laboratory activity in groups. It is assumed for this research that, while the distribution of students to groups may not be random, the assignment of the groups to the treatment or control groups are random and as such the samples can be considered randomly assigned.

For the statistical analysis it is assumed that treatment and control groups have equal variances in their data.

A requirement for the laboratory activity was that the pretest and lab assessment be completed individually. This research is considering the impact on students' individual learning and so collaboration is a confounding factor. Care was taken in the research design to see where there was collaboration and plagiarism between group members by way of observation of student behaviour in the labs and the inspection of the responses. In assessing whether there was collaboration, the responses of group members were compared and analysed (copying is much more likely for students sitting alongside each other (Harpp & Hogan, 1993)). For long response questions, where the answer wording was identical, collaboration or plagiarism was assumed. For short response questions as in the pretest, more than two different answers between the three group members was required to be considered a unique response. This was based on indications from the literature review that fewer than 15% difference in answers for multiple choice questions is an indication of copying (a conservative approach given the small number of multiple choice questions) (Harpp & Hogan, 1993).

A consideration in a constructivist approach to learning is the individual differences between students. For this research there is limited data collected on learning styles, students' abilities or demographics. These were not used in the analysis of the data and are out of the scope of this research but present an opportunity for further findings to be extracted from the data gathered here in future analysis (such as variations in outcomes correlated to gender or the participants' university entry scores).

Inherent in the pretest-posttest control group design is the effect that pretesting poses to the external validity of the results. This is discussed further in section 6.2.2 but the administration of the pretest does present a limitation to how far the results of this research can be generalised.

6.1.6 Measurement of Variables

Previous research into evaluating laboratory effectiveness has identified exam scores (particularly for those questions testing knowledge and skills taught in the lab activity) and laboratory assessment scores as providing strong indications of what has been learnt (Nickerson et al., 2007). In this research, the laboratory assessment score has been used as a measure of the identified learning outcome (the dependent variable), and in line with the pretest-posttest control group design this must be assessed in a pretest before the treatment, and again in a subsequent posttest.

Information for this research was captured through the use of: the compulsory, individually completed pretest; the compulsory, individually completed laboratory activity (including the posttest); an optional research questionnaire completed by each group; and observation during laboratory sessions. All the work for this was done within the laboratory session (there were no pre-laboratory tasks assigned as part of this research).

Development of the laboratory assessment began from the identification of the strengths and limitations of the inverse square model as a predictor of real-world behaviour (which is core to the targeted learning outcome) which are detailed in section 4.1.3.1.

Consideration was given to how best to take quantifiable measurements of the students' ability to identify each of these strengths and limitations. In line with the results from the literature on research design (section 3.3) the knowledge test drew questions from existing test items where possible (from UQ and Northwestern University laboratory activities using the remote radiation laboratory). While favouring a shorter test because of the time limits of the laboratory sessions, the assessment also included longer, more probing questions as well as short-answer questions.

6.1.6.1 Pretest Assessment

The pretest consisted of two sets of TRUE/FALSE questions. The statements were phrased so that the correct responses would be a mix of 'TRUE' and 'FALSE'. The questions were then reviewed by the course coordinator for ambiguity and appropriateness for the learning outcomes expected from the students in the first year subject.

The first section required participants to determine whether 16 statements concerning the experiment and its results were true or false. Twelve of these statements related directly to the strengths and limitations of the inverse square model, while the others related to the nature of the laboratory. These questions are listed in Table 6.1 with the correct answers indicated.

Table 6.1: Pretest question 1.

Question 1. Considering the radiation experiment you are about to complete, for each of the following statements, please select whether they are 'TRUE' or 'FALSE'?

	Statement	**TRUE**	**FALSE**
a.	The predicted values for the experiment will be incorrect as the model does not take into account background radiation from the environment.	X	
b.	Radiation from our computers or phones will affect the results so there will not be an inverse-square relationship.		X
c.	The theoretical prediction of an inverse-square relationship is an approximation only so results will not match exactly.	X	
d.	Radioactive decay is random so the results will not match the inverse-square law exactly.	X	
e.	Taking shorter measurement times will mean there is less chance of errors in the data so the results will show the inverse-square law better.		X
f.	The experiment equipment is far away so we cannot know if it is working correctly.		X
g.	Delay caused by situating an experiment remotely mean that the results will not be the same as if the equipment were in the lab.		X
h.	Running more trials of this experiment means there is more chance of errors occurring and results will be less accurate.		X
i.	Radiation absorbed by the environment in the remote laboratory will affect the results so we may not get exactly an inverse-square relationship.	X	
j.	Incorrectly plotted data means the results may be incorrect	X	
k.	Inverse-square is a LAW so there should be no difference between the theoretical prediction and the measured value unless the experiment is incorrectly done.		X
l.	The inverse-square relationship we find will be applicable only to our radiation source (Strontium-90). Other types of radioactive materials MAY have a different relationship.		X
m.	Background radiation is taken into account in predicting the values so this will not affect our values at all.		X
n.	If the experiment was performed in a vacuum chamber, the values would be the same.		X
o.	If there was a lead shield behind the strontium source, the results would still show the inverse-square relationship.	X	
p.	If there was an aluminium panel in front of the strontium source, the results would not be affected.		X

The second section required participants to identify which of 11 real world phenomena displayed the same inverse square relationship between distance and intensity, specifically targeting S1. These questions and the answers are listed in Table 6.2.

Table 6.2: Pretest question 2.

Question 2. Select 'TRUE' or 'FALSE' for each of these phenomena or applications which you think would have the same relationship between 'intensity' and 'distance from a source' that we expect to find in our radiation experiment?

	Statement	**TRUE**	**FALSE**
a.	Intensity of light from the sun	X	
b.	The speed of a car in relationship to how hard the accelerator pedal is pushed		X
c.	Level of radiation from an X-ray machine	X	
d.	Brightness of a perfectly focused laser beam		X
e.	Speed of a skipping rope		X
f.	Strength of gravity	X	
g.	Height of waves in a pool when a stone is thrown in		X
h.	Phone signal strength from a cell phone tower	X	
i.	Speed of a ball thrown straight		X
j.	Volume of sound from a microphone	X	
k.	Turbulent flow from an aeroplane wing		X

The relationship between these questions and the identified strengths and limitations of the model are shown in Table 6.3 below.

Table 6.3: Mapping between pretest questions and the strengths and limitations that they measure

	Question 1	**Question 2**
S1	l	a-k
S2	c,e,h	
L1	a,b,m,n	
L2	b,i,n,o,p	
L3	c,d,e,h	
All strengths and limitations	a,b,c,d,e,h,i,l,m,n,o,p	a-k

The pretest as given to participants is included in Appendix E.

6.1.6.2 Laboratory Activity and Posttest

As part of the laboratory assessment, participants were required to decide on execution parameters for the laboratory (these were how many trials, how many measurements and how long to take measurements for). They executed these on the remote radiation equipment and were then required to plot and interpret their results in the lab assessment which included the posttest for this research.

The questions detailed above for the pretest were repeated in the posttest. Also included in the posttest assessment were four longer questions that gave participants an opportunity to illustrate an understanding of the strengths and limitations of the inverse square model as investigated within the laboratory activity. The longer questions allow the participants to communicate a deeper understanding and to compensate to some degree for the risk of guessing in the TRUE/-FALSE answers. They were used only in the posttest to evaluate improved understanding and as they required laboratory results, they could not be included in a pretest.

The details of the laboratory assessment are included in Appendix G. The questions asked for the posttest were:

1. **Question 1a:** Based on the data collected how would you describe the relationship between the particle count and distance from the source? Why?
2. **Question 1b:** Does your graph accurately illustrate theoretical relationship between radiation particle count and the distance from the strontium-90 source?
3. **Question 1c:** How would you change your experiment to improve the fit between theoretical prediction and measured values?
4. **Question 2:** Repeat of pretest questions as described in Table 6.1
5. **Question 3:** Repeat of pretest questions as described in Table 6.2
6. **Question 4:** Choose one of these phenomena [from the list in the TRUE/FALSE questions] and suggest an experiment that could be used to investigate this.

6.1.6.3 Research Questionnaire

The research questionnaire was designed to determine whether the groups conducting the remote laboratory in the contextualised virtual world experienced additional difficulty completing the tasks, and whether their attitude to the laboratory was in any way different to that of the control group in terms of their perceived learning outcomes and enjoyment of the lab activity.

Seven five-point Likert-type items were used to measure qualitative perceptions of the remote laboratory and virtual world and the associated learning. Additionally five open-ended questions allowed participants to record additional experiences, perception and preferences for the remote laboratory activity over a hands on lab. The questions from the questionnaire are reproduced in Table 6.4 (and included, as given to students in Appendix H.)

The questionnaire was completed by each group, not by individual participants, at the conclusion of the laboratory activity (and was optional).

Table 6.4: Research questionnaire

	Statement	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1a.	In general, the virtual world was easy to use.					
1b.	We enjoyed the laboratory activity more because of the virtual world.					
1c.	We learnt more from this laboratory because it was in a virtual world.					
1d.	We would like to see a more realistic world when doing the laboratory.					
1e.	We found the virtual world a distraction when doing the laboratory activity					
1f.	It is a good idea to use a remote laboratory for this laboratory activity.					
1g.	It was difficult to understand the laboratory because the equipment was remote.					
2.	If you have had difficulties executing this lab in terms of (a) navigating the virtual world and/or (b) controlling the remote laboratory, please describe them.					
3.	Do you think there was anything in this laboratory you learnt that you would not have learnt if it had been a traditional hands-on laboratory?					
4.	How did your experience change (either positively or negatively) because of the use of the Open Wonderland virtual world in this laboratory activity?					
5.	Would you like to do more laboratories in a virtual world?					
6.	Would you like to use more remote laboratories?					

The results of a comparison between the treatment and control group responses could provide an indication of possible differences between the groups' perceptions and possibly indicate further avenues for investigation and research.

6.1.6.4 Laboratory Observation

The laboratory activity was observed by the researcher and tutors to determine whether the participants were successfully completing the laboratory activity as described. The observations were recorded informally during each of the laboratory sessions.

The laboratory groups were monitored to see whether any of them engaged with the virtual world and the remote laboratory in any way not specified by the laboratory guide. Additionally, any questions asked by the participants, or any noticeable difficulties conducting the laboratory, were noted.

The information gathered was considered valuable for providing an additional input into analysing the perceptions participants have of the laboratory activity. Also, where the behaviours affected the laboratory, this was taken into account for the result analysis (such as one group leaving their non-contextualised space in the virtual world and navigating to a contextualised space).

6.1.7 Data Capture and Collection Process

All data was collected in one afternoon over two laboratory sessions, each of which was two hours long. The participants were assigned to one of the laboratory sessions and worked in their self-selected groups at one of 18 computers within the laboratory classroom. The assignment of each laboratory group to either the treatment or control groups was done randomly, with half the computers in the laboratory room having the contextualised virtual world (making up the treatment group), and the other half having the non-contextualised world (the control group).

In order to ensure the participants could not be identified in the data, responses were distinguished by the computer number at which they conducted the experiment, whether they were part of the first or second laboratory session, and then by a number (1,2 or 3) for each member of the group. For example identifier **PHYS136-1-3** indicates the participant who worked on the computer **PHYS136** (each computer in the lab has a unique name), and was part of the first laboratory session indicated by the **1** and that they were group member **3** (this is random depending on the laboratory handout each participant selected when seated). The results were correlated back to either the treatment group or control group by the computer number as listed in Appendix section I.1.

Participants completed the pretests individually and these were collected before any laboratory activity was begun. Participants conducted the lab activity in their groups by following the laboratory activity guide. The participants were required to complete the lab assessment individually. Once complete, each group was requested to fill out the research questionnaire assessing their impression of the laboratory activity experience. Throughout the laboratory activity, participants were observed by the researcher and tutors. Any questions asked by the groups were noted, along with any interaction the students had within the virtual world that was not part of the laboratory activity.

Following the laboratory, the pretests and posttest were marked according to a pre-defined rubric by this researcher. The responses to the short questions, as well as the marks to the long questions and the research questionnaire Likert-type items and valid long responses were captured electronically, with the participants' identification removed (each response was identified using the unique ID generated as above, per participant and per group as necessary).

A few of the reports submitted showed copying of some kind and these results were excluded from the quantitative analysis of the results according the criteria established in the experiment design (that is that participants within a group require at least 15% of their answers to be different in order to have confidence of no copying, see section 3.3.2). For long response questions, where collaboration or plagiarism was assumed, only one of the copied responses was included for the statistical analysis. For short response questions as well only one of the responses was included, and for those questions where answers differed, the researcher selected the response given by the majority of the group.

Many of the long responses for the research questionnaire were not completed with any useful information, and these were also excluded from the analysis. It is believed that the lack of useful responses was due to the fact that the questionnaire was an optional activity completed at the end of each lab session and was not included as part of the lab assessment tasks, so was treated more casually by the participants. The responses were not planned to be part of the hypothesis testing but the lack of information presents a limitation for the study. Completed long response questions were captured to determine whether any comments or trends would support or contradict conclusions drawn from the Likert-type items.

6.1.8 Data Analysis and Interpretation Process

6.1.8.1 Laboratory Assessment

The pretest-posttest control group research design used here lends itself to analysis with a *t* test (Campbell et al., 1963; Norman & Streiner, 2003). This tests the statistical significance of any difference between the control and treatment groups to indicate with predefined statistical certainty whether the null hypothesis can be rejected.

The differences in the pretest and posttest scores for the repeated questions were calculated for all valid responses. A two-tailed test was selected as it was not known in advance in what direction any differences between the means would be. An unpaired two-tailed *t* test was conducted on the means of the two sets data.

The *t* test output was a p-value describing whether there was a significant difference between the means of the treatment group and control group score differences. For a confidence interval of 95%, a p-value of 0.05 was required for statistical significance. This also indicates an alpha level of 0.05, the chance of incorrectly rejecting the null hypothesis (or a Type I error). For this research, a power value of 0.8 (or an 80% probability of correctly rejecting the null hypothesis if it is false) was selected which is common practice in the discipline. This means a beta value of 0.2 for Type II error.

For an effect size of d = 0.5 (medium effect), the treatment and control groups required a minimum of 34 participants. Once invalid responses were eliminated, the treatment group comprised of 44 subjects, and the control group had 36, meeting the requirements for sample size in detecting an effect of the treatment.

6.1.8.2 Research Questionnaire

The Likert-type items in the research questionnaire were analysed by comparing the frequency of each response between the control and treatment groups. The results were compared by grouping the results into ‘positive’ (agree or strongly agree) or ‘negative’ (disagree or strongly disagree) responses graphically. Half of the neutral responses were assigned to each of ‘positive’ and ‘negative’ groups in order to display the data in such a way that the charts in section 6.3.5 are centred in the middle of the neutral group and trends can be more easily discerned visually. The results were inspected for discrepancies between the two groups. The differences between the responses were considered to determine whether any trends or insights can be drawn from the results. Differences between the control group and the treatment group could indicate an avenue for future research.

6.2 Validity

The selection of the research study design has an impact on the validity of the findings. In order to determine the applicability and usefulness this research it is necessary to test the validity and reliability of the study and the results. Validity concerns whether the research is accurately measuring what it purports to measure. Section 3.3 details the threats to internal and external validity that are common in research. The selection of the pretest-posttest control group research design is justified in section 3.4.4 as mitigating many of these threats. However, consideration must still be given to the specifics of this empirical investigation, which has distinct confounding variables that present a threat to validity.

6.2.1 Internal Validity

For research to have internal validity, it is required to show that the changes of the dependent variable are a result of changes in the independent variable and not due to other factors. According to Campbell et al., 1963 the pretest-posttest control group design controls for the effects of history, maturation, testing, instrumentation, regression, selection, mortality and interaction between these factors on internal validity. While not all of these are relevant to this study (such as mortality), a number of these factors were given additional attention in the empirical research design, along with other recognised threats to validity.

6.2.1.1 Novelty effect

This is the effect that performance can improve when a new technology is introduced due to the novelty of using the technology rather in response to the treatment. In this research the new technology is the integrated remote laboratory and virtual world platform.

The remote lab and virtual world are new to all participants as a mode of delivery for a laboratory activity in this course (as indicated on the research questionnaire responses). The novelty effect was controlled for by requiring both the control and treatment groups to complete the laboratory within a virtual world, so that there is no difference between the groups in the mode of delivery. This step helped to ensure that the effect of the novel technology was consistent across both groups. However, the contextualised world is richer than the control group virtual world and may therefore be more novel and engaging for students (a possible amplification of any effect). It may, conversely, provide more of a distraction (and so attenuate the effect of the treatment).

While the lab conditions aimed to make the experience that participants in the control group and the treatment group experienced as similar is possible, and therefore the effects consistent across both groups, this does not guarantee that measured outcomes are not affected (and improvements either exaggerated or masked) by the novelty effect. The nature of this research in including a novel lab format means that is largely unavoidable, but these limitations to the validity of the research must be considered when analysing the findings, especially as the literature has identified the often small effects reported in educational research.

6.2.1.2 Hawthorne effect

This effect suggests that outcomes from research participants may improve due to the fact that participants know they are being observed and measured. To help ensure that the effect was constant across both groups, the treatment and control groups were mixed together between the laboratory sessions and received the same high level explanation that their results may be used for research. Participants were not informed of the expected outcomes of the research nor made aware of the difference between the treatment and control groups.

For this research it was necessary that participants receive information about their voluntary participation in the research in order to comply with ethics procedures. This means that there is a risk that the Hawthorne effect may play a role in the results and should be considered in their analysis.

6.2.1.3 Selection bias

Selection bias describes biased results due to the non-random selection of participants for each of the control and treatment groups. For this research, the laboratory groups were self-selected and therefore there may be bias in the abilities of each group, however the assignment of the groups to the treatment or control groups are random (based on where they sit in the laboratory classroom) and as such the participants were be considered to be randomly assigned.

The effect of working in groups however, must be considered as a possible limitation. There is research into effective group selection and the effect of collaboration in laboratory environments (for example Mujkanovic and Lowe (2012); Machotka and Nedic (2008)) and teamwork is one of the identified learning outcomes for laboratories, emphasising its' importance (Feisel & Rosa, 2005). The effectiveness of certain groups, and the attenuation or amplification that group work may have on individuals' learning outcomes may have an effect on the results for this research.

6.2.1.4 Instrumentation, maturation, testing and experimenter effects

These describe the bias in results resulting from participants being subjected to different conditions between the first (pretest) and second (postests) measurements taken. In the case of this research, although there were two laboratory sessions, the control and treatment groups were split across both these sessions evenly. Each session made use of the same equipment (which did not degrade during the session), had access to the same information and testing conditions, and were supervised by the same tutors.

All participants had access to the same support material other than the lab context. The laboratory support given during the lab sessions was confined to those areas that were common between the groups rather than specific to the contextualised laboratory. Tutors could answer questions about the laboratory activity but offer no interpretation of the virtual world or the context, nor how to interact with it. It is argued, therefore, that these factors do not present a significant threat to internal validity.

6.2.1.5 History effects

In Campbell et al. (1963), the history effect refers to events occurring between the pretest and posttests which in this research are consistent between the treatment and control groups as they are mixed within sessions.

However, there is another effect resulting from each participants' personal 'history' (based on constructivist learning theories). It is known from the literature that prior knowledge can affect learning, and in particular, can affect how students construct context (Kokinov, 1999). The participants here have similar levels of knowledge about the content of the remote laboratory and have all completed a similar lab investigating the inverse square model using a light source. The effect of prior knowledge can be considered consistent across both the treatment and control groups to the degree that personal history can be controlled.

6.2.1.6 Motivation effect

Motivation plays an important part in learning and is an individual trait. A student's motivational state can be influenced by other variables such as the nature of the task, incentive to complete the task, personal learning style and preferences. In order to ensure that neither the treatment or control groups were given different motivational drivers to complete the laboratory, no incentive was offered to either group for participation in the study. All participants were required to complete the laboratory as a course requirement but participation in the study was voluntary and anonymous.

6.2.2 External Validity

External validity describes the degree to which the results can be said to apply to cases other than the research study. In order for this research to be externally valid, consideration must be given to whether the results can be generalised for others in the population, that is other students learning the inverse square law within a laboratory and more broadly, those students learning about models through the use of a laboratory activity. Additionally, it must be considered whether the results can be generalised to other laboratory formats, modes of delivery and laboratory environments.

The major factors in external validity are whether the sample students are representative of the population and whether the laboratory is representative of other labs. Campbell et al. (1963) identify the threats posed by using a pretest and the 'reactive arrangement effect' for the pretest-posttest control group design.

6.2.2.1 Student Sample

In this case, the selection of participants were typical of undergraduate university students learning in laboratory environments. They are all enrolled in a course that includes laboratories as learning activities, and which has identified the targeted learning outcome for the laboratory exercises. According to the academic delivering the MRTY1036 module, students within the course had achieved relatively high university entrance requirements but had diverse science and physics levels and therefore most probably diverse exposure to the nature of laboratories (J. OByrne, personal correspondence, August 2014).

6.2.2.2 Laboratory as a Sample

For the results to be applicable to other laboratory activities, the sample lab must be shown as being representative of those other laboratories. Consideration of the laboratory includes many factors such as the underlying model, the type of lab and of experiment, the laboratory environment and the level at which it is aimed.

Type of laboratory: This research involves a new integrated remote laboratory and virtual world system. This was selected because it provides a computer interface that can be used to add rich contextual information to a laboratory activity. Domain context does not always need to be done via a computer interface, but can be added in the hands-on environment through supplementary information, or elements in the lab environment.

Additional consideration was given to the nature of the laboratory. While the delivery mode of a laboratory has been shown to have an effect on learning outcomes, the targeted laboratory learning objective of understanding models can be achieved using remote labs as effectively as hands-on labs. The perception students have of the laboratory equipment as real (rather than simulated) also influences learning outcomes. For this reason, care was taken to explain and demonstrate to all participants the nature of the remote lab and to provide a live video throughout the lab activity.

It is expected that results obtained in this environment will be applicable to other computer mediated laboratories, but that because the research is targeting a learning objective which is not affected by the remote mode of delivery, conclusions can reasonably be drawn about this same learning outcome for labs with other access modes.

As discussed in section 6.2.1.3, group work plays a role in learning outcomes and must be considered when generalising the results to other laboratory activities, it may be that the results here are best generalised to other laboratory activities completed in small groups.

Type of experiment: The radiation experiment used here is considered a proxy for the real world, allowing students to manipulate variables that would be impractical (and dangerous) in the real world. The experiment can be used to achieve a number of learning objectives depending on the activity assigned to students. The fact that this laboratory is currently used in a number of institutions worldwide to teach a number of different concepts indicates its wide applicability. In this case it is considered typical of undergraduate laboratories and its choice does not limit the applicability of the results to other widely used undergraduate experiments.

Underlying model: The results of the research report information on the learning outcome of being able to identify the strengths and limitations of models as predictors of real-world behaviours, and can be expected to have applicability to those models that include such identifiable strengths and limitations. As most theoretical models that can be investigated in undergraduate labs are idealised or simplified explanations of reality, this is likely to be generally applicable to undergraduate laboratories, providing they aim to achieve a similar learning outcome.

6.2.2.3 Effect of Pretest

The interaction of testing with the treatment in a research study can affect the external validity of the results (Campbell et al., 1963). Pretests can affect attitudes, susceptibility to persuasion and sometimes dampen the effect of a treatment. The effect is a function of how representative pretests are in the population to which the results are to be generalised. In laboratory learning environments, testing is common and while a formal pretest before a laboratory is not commonplace, students are often asked to predict results of experiments before conducting lab measurements either in pre-work or during a laboratory. For this reason, it can be argued that the results can reasonably be generalised to other laboratory learning environments in spite of the pretest.

6.2.2.4 Reactive Arrangement Effect

Often the artificiality of a testing environment can limit the generalisation of the findings. Campbell et al. (1963) suggest that educational research be conducted by regular staff in an environment as close to the ordinary as possible to avoid such reactive arrangement effects.

In this case, the laboratory was conducted in the usual classroom and at the usual time of the students' lab sessions. However, the addition of the researcher was out of the ordinary and students were informed of the research study being conducted (as required by the ethics procedure). Participants were not informed of the learning outcome being measured.

It is believed that the reactive arrangement effect has been considered as much as is practical, and that its effect is likely to be small, but the possible influence on learning outcomes must be considered in applying the results to other situations.

6.3 Research Data Analysis

The responses to the pretest and lab assessment, as well as the research questionnaire, were captured and recorded as described by the collection and capture process (section 6.1.7). This section describes and summarises this data and presents the results of the analysis. Appendix I contains a record of the raw data collected and used in the final analysis.

6.3.1 Student Information

Participation in the study was optional and anonymous in order to comply with the ethics requirements of the host institution for such research. Students were given an introduction to the laboratory and offered information concerning the research study. All students in the cohort consented to participate in the research.

There were 97 participants in 33 groups. The treatment group had 50 participants in 17 groups, while the control group had 47 participants in 16 groups. All the participants completed the pretest and laboratory assessment (posttest).

One group (PHYS148-1) had navigated within their virtual world from a non-contextualised space to the contextualised space. They were included in the treatment group as they had explored the contextual environment.

There were a number of responses that were excluded because they showed evidence of possible copying between group members, either in the pretest or posttest (details included in Appendix section I.2). This resulted in reducing the sample population to 80 responses in total, 44 in the treatment group and 36 in the control group. The exclusion of data was done according to criteria defined in the experiment design and while it had the effect of reducing the control group by a larger percentage than the treatment group, the final sample numbers fall within the requirements of at least 34 participants for each group for a statistical power of 0.8.

One lab group from the treatment group did not complete the research questionnaire, resulting in 16 responses from each of the control and treatment groups for the questionnaire.

6.3.2 Pretest Information

The pretest results are summarised in Table 6.5. The table shows the mean values and standard deviations for the number of correct answers to each of the strengths and limitations questions. It should be noted that the number of questions that address each of the strengths and limitations differs as described in Table 6.3. The data for both the treatment group and control group is shown. On first inspection, the means and standard deviations are similar between the groups. The detailed results of the number of correct responses to each of the questions in the laboratory pretest are presented in Appendix I.3.

Table 6.5: Pretest mean values and standard deviations for the number of correct responses to questions assessing the understanding of strengths and limitations

		All strengths and limitations	**S1**	**S2**	**L1**	**L2**	**L3**
Treatment Group	**Mean**	16.432	8.545	2.409	2.659	3.477	3.182
	Std Dev	2.482	1.758	0.693	0.914	1.045	0.843
Control Group	**Mean**	16.583	8.722	2.417	2.472	3.583	3.278
	Std Dev	1.826	1.632	0.732	0.878	0.967	0.815

6.3.3 Posttest Information

The posttest results are summarised in Table 6.6. The table shows the mean values and standard deviations for the correct answers to each of the strengths and limitations questions. As for the pretest, the number of questions that address each of the strengths and limitations differs as described in Table 6.3. The data for both the treatment group and control group is shown. Again, a first inspection shows the resulting mean values to be similar, but there is a noticeable difference in standard deviations. The difference in standard deviations is accounted for when determining the statistical significance of changes in test scores by the application of the *t* test to the paired results. However, these difference present an avenue for future work, possibly looking into whether students with different learning styles respond differently to context. Detailed results of the number of correct responses to each of questions in the laboratory activity posttest are presented in Appendix I.4.

6.3.4 Paired Results

In order to test whether the null hypothesis can be rejected, the results of the treatment group and control groups must be compared to determine whether there is any statistically significant difference between the results. The pretest and posttest results were paired to calculate the

Table 6.6: Posttest mean values and standard deviations for the number of correct responses to questions assessing the understanding of strengths and limitations

		All strengths and limitations	**S1**	**S2**	**L1**	**L2**	**L3**
Treatment Group	**Mean**	16.136	8.909	2.000	2.591	3.500	2.727
	Std Dev	3.137	2.197	0.778	1.106	1.285	1.042
Control Group	**Mean**	16.861	9.139	2.333	2.639	3.528	3.139
	Std Dev	1.885	1.496	0.586	0.833	0.910	0.762

change in scores between the pretest and posttest for each participant. The results were grouped by each of the identified strengths and limitations of the inverse square model as a predictor of real-world behaviours. In reading the absolute values for the means and standard deviations of each strength and limitation, the differences in the number of questions which address each one (as described in Table 6.3) should be considered.

In order to apply the statistical tests, the mean values of the differences for each group were used as the data for an unpaired two-tailed *t* test. Possible statistical significance was determined with a 95% confidence interval, therefore a p-value of < 0.05 was considered significant.

Table 6.7: Comparison of the control group and treatment group mean and standard deviations for the paired pretest and posttest difference in scores. The resulting p-values are also given for each of the strengths and limitations and the combination of all the strengths and limitations.

			All strengths and limitations	**S1**	**S2**	**L1**	**L2**	**L3**
Treatment Group	**N=44**	**Mean**	-0.30	0.36	-0.41	-0.07	0.02	-0.45
		Std Dev	2.45	1.53	0.87	1.13	1.32	0.98
Control Group	**N=36**	**Mean**	0.28	0.42	-0.08	0.17	-0.06	-0.14
		Std Dev	1.94	1.00	0.77	0.91	1.26	1.07
p-value			0.26	0.86	0.08	0.32	0.79	0.17

The results, as presented in Table 6.7, show that the difference in learning outcomes was not statistically significant with $p > 0.05$ for all the questions assessing participants ability to identify the strengths and limitations of models, as well as the combination of all the strengths and limitations. The results did not improve for either group. This result has a 95% confidence interval and a power of 0.8.

A further unpaired two-tailed *t* test was done on the data excluding those questions which measured the limitation concerning the stochastic nature of radioactive decay (L3). This was done to get an indication of the possible effect that the technical limitation of the inability to develop the scaled up atomic model or the simulated Geiger counter for the context (both of which were designed to address this limitation of the inverse square model) may have had on the study outcomes. The result of the technical limitation meant that, for context addressing L3 particularly, the control and treatment groups' experiences were very similar. The analysis resulted in a p-value of 0.32 ($p > 0.05$) indicating no statistically significant difference between the control group and treatment group outcomes even when ignoring L3.

There are observations that can be made from the changed in responses to some of the questions in the pretest and posttest. Question 2j. from the pretest (which asks participants to determine whether the volume of sound from a microphone has the same relationship between 'intensity' and 'distance from a source' that is found for radiation) shows that the correct answers from the control group dropped from 25 (of 36 respondents) to 19, while those for the treatment group increase from 32 (of 44 respondents) to 38. The result from the single question cannot provide statistically significant conclusions, but this result does indicate that further research could look into whether the control environment potentially implants misconceptions while the treatment environment corrects them. Further work can be done in mining the data to see, at a question level, whether the averaged results mask a large number of changed responses and what factors may have had an effect these.

For the longer questions in the posttest, there is no pairing available so the means of the treatment and control groups were compared using a two-tailed *t* test. This resulted in a p-value of 0.56 (> 0.05) indicating no statistically significant difference between the groups.

The conclusion from the statistical analysis is that *the null hypothesis cannot be rejected*. That is, the data collected does not indicate that there is a statistically significant difference between participants' ability to identify the strengths and limitations of theoretical models as predictors of real-world behaviours as learnt in an environment that includes domain context, and one that does not.

6.3.5 Research Questionnaire Information

As an indication of possible differences in student perceptions, the research questionnaire allowed a comparison of the Likert-type items between the control group and the treatment group.

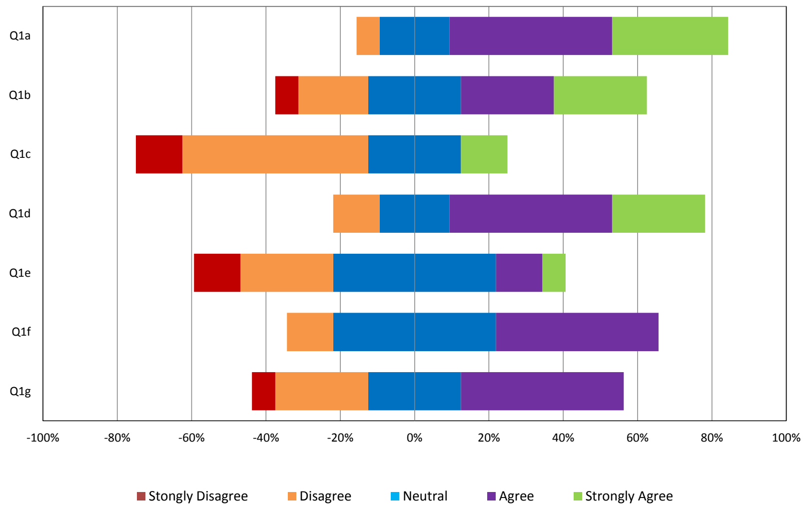


Figure 6.1: Control group responses to research questionnaire illustrated as a ‘positive’ or ‘negative’

The questions have been described in section 6.1.6.3.

One research questionnaire was voluntarily submitted per group with 16 responses each from the control and treatment groups. They were given a choice of five ratings for each question (strongly disagree, disagree, neutral, agree, strongly agree). The percentage of responses in each of the five categories is presented for the control group in Table 6.8 and illustrated graphically in Figure 6.1. For the treatment group this information is presented in Table 6.9 and Figure 6.2.

Table 6.8: Control group responses to the Likert-type items in the research questionnaire

	Total Count	**Stongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Q1a	16	0%	6%	18%	41%	35%
Q1b	16	6%	18%	24%	29%	24%
Q1c	16	12%	47%	29%	0%	12%
Q1d	16	0%	18%	18%	41%	24%
Q1e	16	12%	24%	47%	12%	6%
Q1f	16	0%	12%	41%	47%	0%
Q1g	16	6%	24%	24%	41%	6%

Additionally, the completed open-ended question responses where investigated to see whether they provided any further insight into the findings from the Likert-type questions. There were 10 completed responses from the treatment group and 13 from the control group. The responses are described in Appendix I.5.

Table 6.9: Treatment group responses to the Likert-type items in the research questionnaire

	Total Count	Stongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Q1a	16	0%	19%	31%	44%	6%
Q1b	16	0%	13%	50%	31%	6%
Q1c	16	6%	19%	50%	19%	6%
Q1d	16	0%	13%	13%	56%	19%
Q1e	16	19%	44%	25%	13%	0%
Q1f	16	0%	6%	44%	50%	0%
Q1g	16	0%	38%	44%	19%	0%

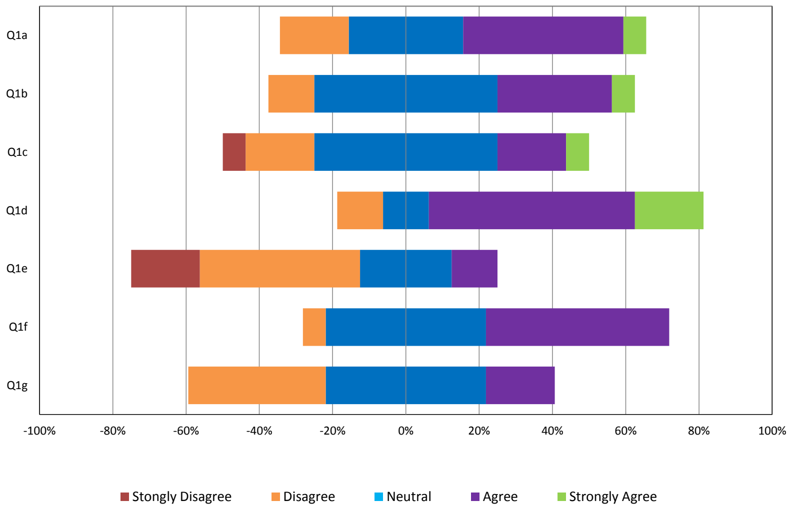


Figure 6.2: Treatment group responses to research questionnaire illustrated as a ‘positive’ or ‘negative’

The responses for each question for the control and treatment groups can be compared to get a broad indication of any differences in participants' perceptions.

6.3.5.1 Q1a. In general, the virtual world was easy to use.

The first statement shown in Figure 6.3 indicates that while the majority of participants in both groups reported that the virtual world was easy to use, there was a difference between the control and treatment groups. The treatment group reported more negative responses. This could be due to the fact that the control group were not required to move through the virtual world to execute the remote laboratory, their avatars were already in place in front of the laboratory interface. The treatment group, however, were required to move from their starting point through the Research Complex created as context, to the lab interface in order to execute the laboratory. The result reflects the more complex navigation required from the treatment group.

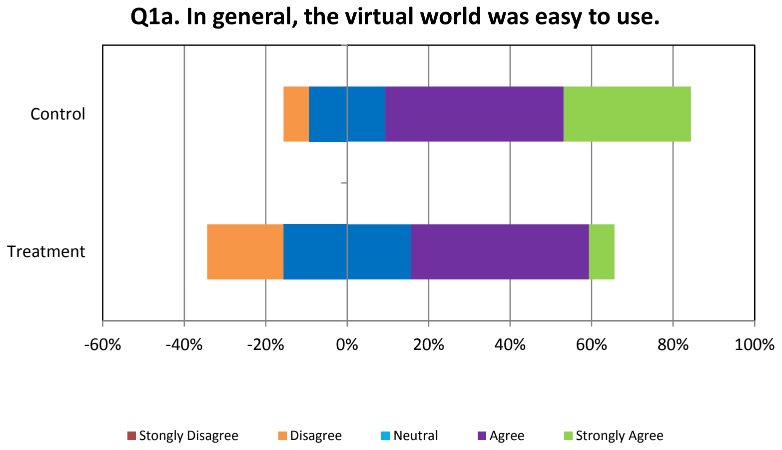


Figure 6.3: Research questionnaire Q1a.

The majority of positive responses is supported by the open-response questions from the questionnaire. Most responses indicated few or no difficulties in executing the laboratory and, where there were difficulties, these mostly had to do with the lag of the system (Question 2.). One response from the treatment group indicated that they thought the "virtual lab is unnecessarily far" reflecting the more complex navigation.

6.3.5.2 Q1b. We enjoyed the laboratory activity more because of the virtual world.

Participants from both groups reported mostly positive responses to the question of enjoying the laboratory more in the virtual world as shown in Figure 6.4. Looking at overall positive and negative responses, the results are very similar for both groups.

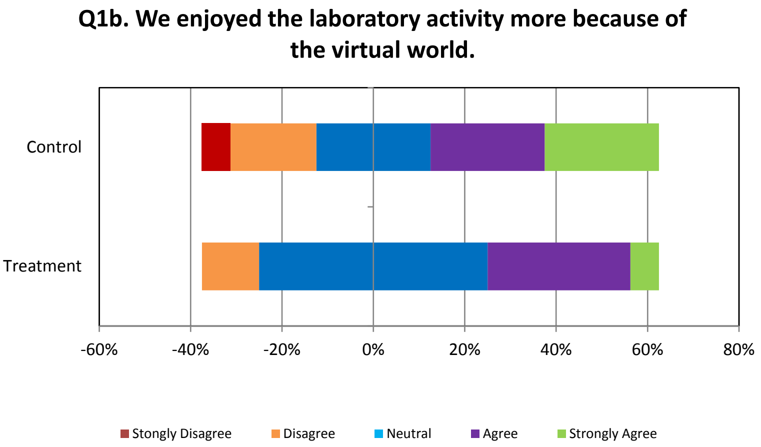


Figure 6.4: Research questionnaire Q1b.

Predominantly positive or neutral responses for both groups to the open-response question concerning their experience in the laboratory (Q4.) support this finding.

6.3.5.3 Q1c. We learnt more from this laboratory because it was in a virtual world.

On participants' perceptions of their own learning, the research questionnaire responses showed that for the control group they were less likely to feel they had learnt more completing the laboratory in the virtual world (shown in Figure 6.5). This is consistent with the control group laboratory design which presented remote lab functionality within an empty virtual world and made no use of the learning affordances of virtual worlds. Interestingly, while the treatment group did in general feel they had learnt more, their lab assessment scores showed no significant difference to the control group for the targeted learning outcome. The contextualised virtual world had some effect on participants' *perceptions* of their learning, but not on the measured outcomes.

The long-response questions do not support indications from Question 1c. of differences in perceptions between the treatment and control group in perceived learning from the laboratory. Long responses from participants across both groups indicate that they felt that there was not anything they had learnt in this laboratory exercise that they would not have learnt through a 'hands-on' laboratory (Question 3.). These results reflect the actual learning outcomes more accurately. Very few groups elaborated on why they felt this way, so it is not possible to get an indication of what could have affected the difference. One factor could be the framing of the questions, with one question attributing the change in learning to the virtual world, while the other used a direct comparison to a 'hands-on' laboratory and thereby drawing attention to a possible alternative form (and one that the participants have had experience with).

Worth noting from the long response questions, is that those questions concerning whether participants would like more laboratories within a virtual world (Question 5.) or more remote laboratories (Question 6.) show a fairly even split of positive and negative responses across both groups. In all but four of the responses, the answers for 'virtual world' and 'remote laboratory' questions were the same, perhaps indicating that students did not consider these two aspects of the laboratory activity separately. This is supported to some degree by the long response question asking about a change of experience as a result of using the virtual world (Question 4.). Responses to Question 4. such as "Good for experiments that involve radiation, reduces risks" or "More convenient to obtain particle count" indicate features pertaining to the remote laboratory were attributed to the use of the virtual world, and perhaps participants were unclear of the differentiation being made in the framing of the question.

The indications are that the research questionnaire may have been improved by making the distinction of remote laboratory, virtual worlds, and a comparator of 'learning more' clearer to participants.

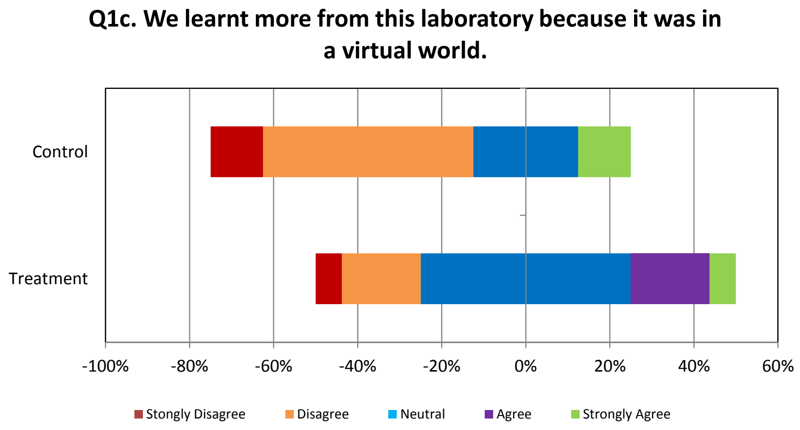


Figure 6.5: Research questionnaire Q1c.

6.3.5.4 Q1d. We would like to see a more realistic world when doing the laboratory.

The control group and treatment group showed very similar responses to the statement concerning a desire for a more realistic virtual world as shown in Figure 6.6 (around 80% for both groups). This is expected for the control group who were shown the empty virtual world, but more significantly, the treatment group also expressed a desire for a more realistic virtual world. This could provide an avenue for further research into the way context should be presented to students in order to engage them best.

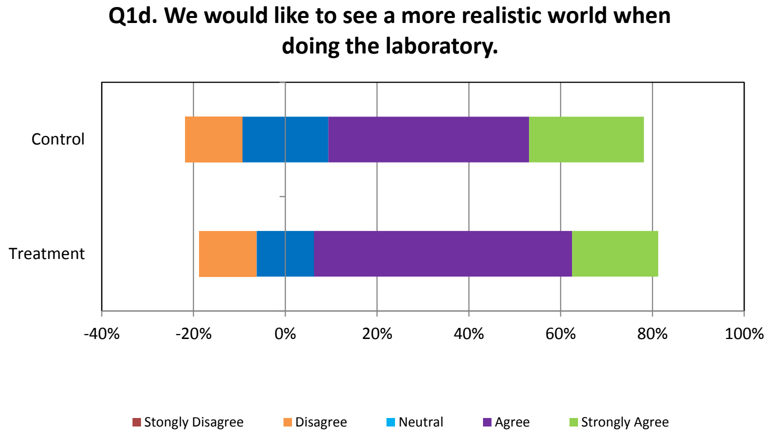


Figure 6.6: Research questionnaire Q1d.

6.3.5.5 Q1e. We found the virtual world a distraction when doing the laboratory activity.

Along with Questions 1a. and 1c. described above, and as shown in Figure 6.7, the statement concerning the distraction caused by the virtual world reveals differences between the control and treatment groups. In this case, most participants did not find the virtual world a distraction but for the control group, there were more participants who did feel it was a distraction. It can be argued that for these participants, because the virtual world was empty and served to present no additional information, having to conduct the remote lab in such an environment was more distracting than beneficial. It is possible that the lack of contextual information for the control group may have focused the participants attention on the virtual world rather than the context. The treatment group, although presented with context that had the potential to distract from the lab activity, found the environment less so.

This result points to increased engagement with the virtual world environment for the treatment group. This can be seen as a positive indication that the participants noticed the Research Complex environment with its contextual information. The increased engagement shown by the treatment group must be considered when determining the validity of the results as an increased engagement will effect learning outcomes.

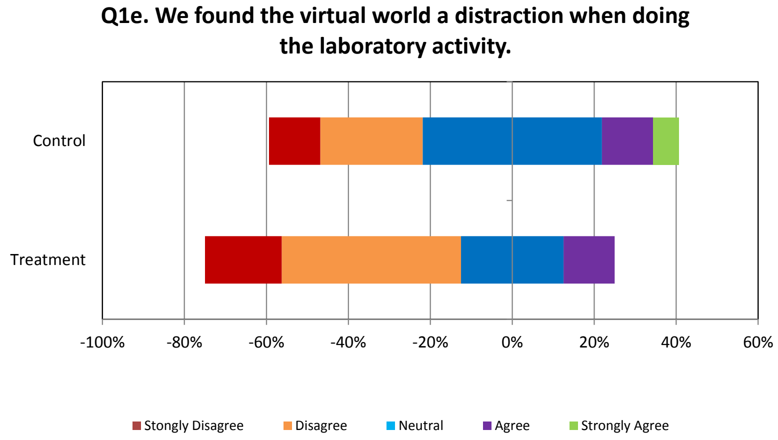


Figure 6.7: Research questionnaire Q1e.

6.3.5.6 Q1f. It is a good idea to use a remote laboratory for this laboratory activity.

Figure 6.8 below indicates very similar, predominantly positive responses for the treatment and control groups to the use of the remote laboratory.

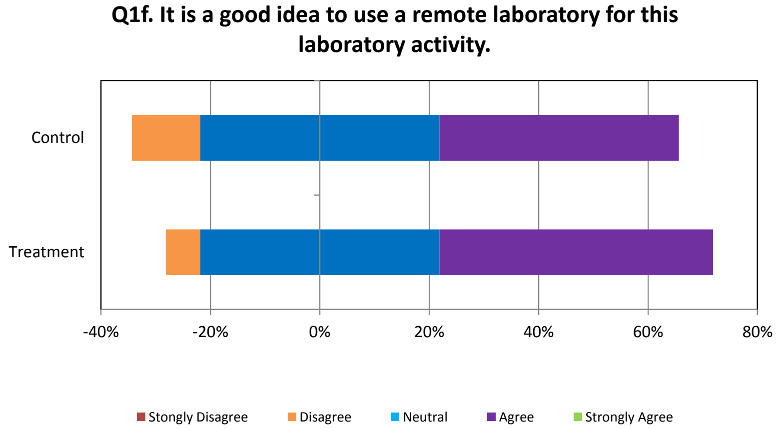


Figure 6.8: Research questionnaire Q1f.

6.3.5.7 Q1g. It was difficult to understand the laboratory because the equipment was remote.

Lastly, on participants' perception of their understanding of the experiment due to the fact that it was remote (shown in Figure 6.8), participants in the control group indicated that they had more difficulty in understanding the lab than the treatment group. Once again, this measures participants' perceptions and is not borne out by the measured outcome. This result, along with their perception of their learning indicated in Question 1c., indicates a positive effect on student perception of understanding from the contextualised laboratory and provides an avenue for future research.

Looking at this result with the results of Question 1f. shows that the a while a larger portion control group found that the laboratory was difficult to understand because of the remote equipment, they were only slightly less likely to support the use of the remote laboratory in this experiment. This is an interesting avenue for further research and suggests that the perceived difficulty in understanding did not detract from their perceived learning or enjoyment of the laboratory.

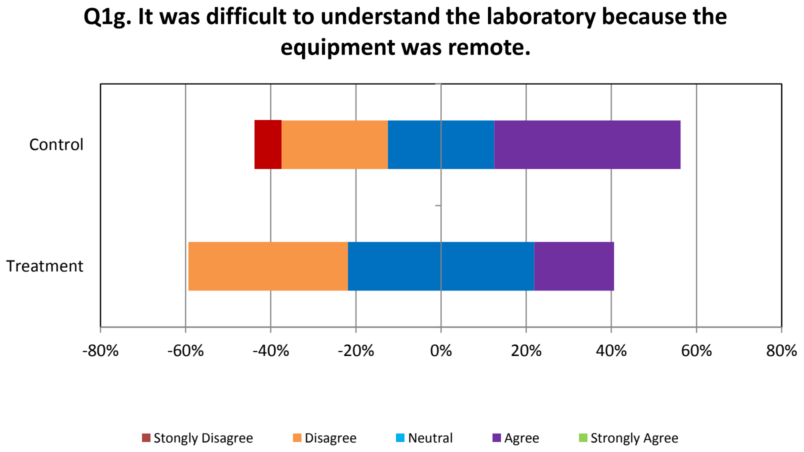


Figure 6.9: Research questionnaire Q1g.

6.3.6 Laboratory Observation

During the laboratory, participants were observed and any questions from participants regarding navigation or technical difficulties within the lab activity were noted and reported back. It was found that two lab groups had trouble with controlling the remote laboratory. One of these lab groups was from the control group and another from the treatment group. Each of these lab groups were given the same set of instructions and help to complete the experiment by this researcher. As the problems were isolated to just two lab groups (and covered both the control and treatment groups) it was determined that this would have been unlikely to affect the final results.

One group, familiar with virtual worlds, navigated from the non-contextualised world to the contextualised one. Their results were counted in the treatment group after this. Two more groups used the tools in the virtual world to change their avatars. This was done once the laboratory activity was complete and therefore did not influence their results.

All the groups executed the laboratory successfully, doing at least one run of the experiment. All the groups were observed to have used the camera panel to observe the radiation experiment too.

6.4 Research Questions Answered

The design of the research study, its implementation and the collection and analysis of results has addressed a number of the research questions posed.

6.4.1 How will the influencing factors be controlled and/or accounted for in the empirical research study and research conclusions?

The design of the empirical research study was considered in terms of maintaining the internal and external validity of the research experiment and the conclusions drawn from the results. The details were discussed in section 6.2 where it was explained how confounding factors and influences are dealt with in detail. The question will be addressed in terms of the analysis of the research findings in 7.1.11, but from the perspective of the research design described here the results can be summarised as follows:

- *Novelty effect*: The technology was new to participants as a mode of delivery for a laboratory activity in this course which it was hoped would make the novelty effect consistent over both the treatment and control groups. Most significantly for the novelty effect was the finding that the control group was more likely to find the virtual environment a distraction (section 6.3.5.5) pointing to the possibility that the richer contextualised environment was novel and engaging for the treatment group participants.
- *Hawthorne effect*: This effect suggests that outcomes from research participants may improve due the participation in the research and the fact that participants know they are

being observed and measured. In this study all participants received the same information about their voluntary participation in the study and the use of their responses as part of the research and none were given an indication of the learning outcome that was relevant to this research. In addition, the researcher was present in both laboratory sessions.

- *Selection bias*: The self-selected groups generally performed well together with the only noticeable difference being two groups who struggled with navigating through the world and controlling the lab (one group each from the treatment and control groups). The effect was that the struggling groups took longer to complete the lab with more tutor support required, but there were no questions or concerns raised about contextual elements or laboratory content by this group. Where there was obvious collaboration in the lab activity responses within a group, the copied results were excluded so as not to influence the results.
- *Instrumentation, testing and experimenter effects*: The instrumentation and testing methods were consistent over both groups. The assessment criteria was defined before the laboratory sessions so that there was no bias. All participants had access to the same support material other than the lab context and tutors were instructed to answer only questions about the laboratory itself, not about the context.
- *History effects*: In the study design, the fact that all participants had already completed a laboratory investigating the inverse square law with a light source was believed to ensure that the history effect would be consistent across both groups and not confound the results. It is, however, possible that this exposure to another inverse square phenomenon within a laboratory environment means that the effect of the domain context on learning was diminished. While contextual elements in the Research Complex such as the 'light laboratory' were designed to link to the existing knowledge participants gained from the previous lab activity, it could be that the control group participants were also able to make a link to this knowledge prompted by the domain context intrinsic in the radiation laboratory, or even the situational context of physically performing a lab required for this course.
- *Motivation effect*: While this influence cannot be completely controlled for, students were given no inducement to complete the laboratory or participate in the research study (such as gifts) and all were required to complete the laboratory assignment as a course requirement so that all participants had similar motivational drivers to complete the tasks. In order to provide an indication of students' perception of the virtual world and the remote laboratory, participants were asked to complete a research questionnaire in which they rated their experience of the virtual world and remote laboratory system.

In order for this research to be externally valid, consideration was given to whether the results can be generalised for others in the population, that is other students learning the inverse square law within a laboratory and more broadly, those students learning about models through the use of a laboratory activity. For this, the student sample is required to be representative of other student populations, and results from this laboratory activity argued to be generalised more broadly. Once again, from the perspective of having completed the research, it is required to look at these samples and determine validity.

- *Student sample*: The student cohort was typical of undergraduate students required to complete laboratories as coursework.
- *Laboratory as a sample*: The integrated system of remote laboratories in virtual worlds is a justifiable mode of delivering lab activities as determined through synthesis of the literature. Conclusions drawn about the role of context in this environment can be applied to other remote labs, and laboratories in virtual worlds, and with consideration to hands-on labs providing context. It is most applicable to laboratory activities done in small groups. The radiation laboratory itself, and the underlying inverse square law being investigated, are also representative of the type of laboratory and model that undergraduate students will use to investigate the strengths and limitations of models as predictors of real-world behaviour.
- *Effect of pretesting*: It was determined that the pretest was representative of other laboratory activities which ask questions of students before the lab execution (such as predictions of results and other prework) and therefore this does not limit external validity of the results.

There are a number of factors which have been identified as affecting learning outcomes, such as students' preferred learning styles, on which data was not collected. In addition, the results were not analysed in terms of the participants' demographic information such as age and gender. This was not within the scope of this research project but further work in the area could include an investigation into any significant variations that correlate with student differences.

6.4.2 How can improvements in students' ability to identify the strengths and limitations of models as a predictor of real-world behaviour be measured?

This is a broad question concerning the assessment of learning outcomes. The design of the pretest and posttest was described in detail in section 6.1.6.

Each of the identified strengths and limitations was addressed (amongst other questions) in a pretest given to participants before the laboratory, and again as part of the lab assignment. The tests drew questions from existing assessment items where these existed and were suitable.

The format of the test favoured shorter questions because of the time limits of the laboratory sessions. These were a number of TRUE/FALSE questions which were exactly the same in the pretest as the posttest. The posttest assessment also included longer, more probing questions which were included to compensate for the effect of guessing in the short questions, and as part of the laboratory requirements from the course lecturer.

Input for the assessment items was given by academics who had used the laboratory in teaching previously, as well as the lecturer taking the course being used for the study.

The differences in pretest and posttest scores were used as a measure of the change in understanding of the strengths and limitations of models.

This research question is discussed further in section 7.1.12 in light of the research findings.

6.4.3 How will it be determined whether students' understanding has improved after completing the laboratory?

The difference in pretest and posttest scores was used as an indication of improved understanding. A test of statistical significance was done on the results to determine whether there was any difference in learning outcomes between the treatment group and control group that can be attributed to the context rather than chance. A suitable method identified by Campbell et al. (1963) and Norman and Streiner (2003) is the use of a two-tailed unpaired t test on the set of means and standard deviations for paired control group differences and treatment group differences between the repeated pretest and posttest questions. This was done for each of the identified strengths and limitations individually, as well as for the combination of all of them.

In this research, none of the p-values calculated indicated statistical significance, and the null hypothesis was not rejected. No evidence was found that showed that contextualising laboratory activities helps students' performance with respect to the model laboratory learning outcome, rather it was found that there are cases where the contextualisation of laboratories does not affect this learning outcome.

This question is addressed briefly again in section 7.1.13.

6.4.4 Does students' understanding of models improve with the setting of the remote laboratory in a context-rich virtual world over the same laboratory in a non-contextualised world setting?

This research has not shown a statistically significant change in students' ability to identify the strengths and limitations of models as predictors of real-world behaviour due the addition of domain context to a remote lab in a virtual world. What can be stated is that there is a case where the context, despite expectations, does *not* result in any difference in learning outcomes.

This result has implications for how educators develop laboratories and look at laboratory learning outcomes. It is discussed more fully in section 7.1.14 and the implications are explored in section 7.2.

6.5 Chapter Summary

This chapter has detailed the steps, parameters and outcomes of the empirical research methodology applied in this research. In summary:

- A pretest-posttest control group research design was selected. Analysis was done using an unpaired, two-tailed *t* test on the means of the difference in pretest and posttest scores between the treatment group and control group. The confidence interval identified was 95%, resulting in a p-value of 0.05 to indicate statistical significance.
- The dependent variable is the learning outcome targeting models, the independent variable is the context supplied for the laboratory.
- The sample from the population of undergraduate students learning from laboratories was a cohort of 97 radiography students completing the Health Physics and Radiation Biology course at the University of Sydney.
- The learning outcomes were measured using the difference in scores between pretest and posttest questions drawn (where possible) from existing questions measuring students' ability to identify the strengths and limitations of models as predictors of real-world behaviour. The tests included TRUE/FALSE short questions and, in the case of the posttest, long open response questions.
- A research questionnaire measured participants' attitudes and preferences for the remote lab and virtual world using Likert-type items and open response questions.
- Participants completed the laboratory activity in two, two-hour sessions. They were in self-selected groups of two or three students.

- Once possible copying was taken into account there were 80 unique answers in the sample, 44 in the treatment group and 36 in the control group. This fell within the requirements of at least 34 participants for each group for a statistical power of 0.8.
- A number of assumptions and limitations stem from the research design selection which have been explored in this chapter. As far as possible, threats to internal and external validity were controlled for. Some effects such as the novelty effect of the new technology could not be completely mitigated and must be considered when analysing the applicability of the results to other domains.
- The research questionnaire indicated that the majority of participants responded favourably to the laboratory activity and some differences could be seen between the control group and the treatment group in terms of the ease of use of the laboratory and navigation through the virtual world.
- The *t* tests resulted in p-values > 0.05 for each of the strengths and limitations assessed and for the combination of all the strengths and limitations.
- The null hypothesis could not be rejected.

Chapter 7

Research Findings and Discussion

The previous chapter has presented the results of the empirical investigation, finding that the null hypothesis cannot be rejected and, following that, the alternative hypothesis that the context will have an affect the identified learning outcome cannot be confirmed. What can be stated is that there are certain circumstances where relevant domain context makes no difference to the targeted learning outcome. This finding, and the research that leads to it, requires some analysis to understand the implications it may have on learning outcomes for laboratory activities and avenues for future work.

This chapter presents the research findings by addressing each of the research questions again in light of the knowledge gained through this research project. The discussion that follows relates the results of the research back to the existing knowledge in the field and interprets the implications of these findings.

7.1 Research Questions

The research questions that follow from the hypothesis have been answered in part through the various stages of the research process and in this report. Each question is presented here with a reference to the previous discussion which is then briefly summarised and, where relevant, additional insights drawn from the results of the study are added.

7.1.1 Do virtual worlds provide a suitable mechanism for adding contextual information to a laboratory?

Discussed in detail: Section 5.6.1.

Summary: Virtual worlds do provide a suitable mechanism for adding contextual information to a laboratory, although the specifications of the virtual world selected may provide some limitations to the context that can be designed.

Further Conclusions: The implementation described in this thesis has demonstrated a new solution for contextualising a laboratory. While the results of the empirical investigation show no significant difference in learning outcomes between the control group and treatment group, the indications from the research questionnaire were that the context was perceived to some degree by participants and that it altered their experience of the activity. This supports the conclusion that a virtual world does present a suitable mechanism for adding context to the lab. Participants who completed the laboratory in the contextualised virtual world perceived it differently to the control group: they found it less distracting; believed they learnt more because of the virtual world setting; and reported more negative responses to the ease of use of the virtual world.

Looking at this research question from a technical point of view it should be considered whether the development effort and affordances of the virtual world are a necessary or sufficient method of presenting contextual information. Virtual worlds support the development of three-dimensional, interactive environments with which avatars can navigate and engage. While the presentation of context in the case of this research did not take full advantage of these affordances, participants were exposed to a 'realistic' context. Interestingly, both the control groups and treatment groups indicated that they would have preferred a more realistic virtual world in the research questionnaire. Based on the research results, the integrated environment, while effective at presenting the information, may not be sufficient to improve learning outcomes unless more of the affordances of virtual worlds are utilised, possibly using more interactive three-dimensional modelling. Otherwise, context may be presented, and its effects studied, through the standard remote laboratory interface (as for the existing Northwest University remote radiation interface which includes a simulation (Sauter et al., 2013)). If looking at new laboratories in the future, there are concepts that are best explained in three dimensions or not visible in the real world and these may be more suited to presentation within a virtual world.

7.1.2 How can a remote laboratory be accessed through a virtual world?

Discussed in detail: Section 5.6.2.

Summary: The literature review illustrated a number of examples of real equipment being integrated into a virtual world, and a limited number of cases where laboratory activities utilising real world lab equipment were conducted in virtual worlds. This research project illustrates a new, successful solution to integrating iLabs based remote laboratories into the Open Wonderland virtual world.

Further Conclusions: The successful integration of the iLabs based laboratory into Open Wonderland has provided a basis for further research. Further, a re-usable API for interfacing iLabs experiments to Open wonderland has been developed.

There is much scope for exploring further avenues of research that make use of the affordances of virtual worlds (such as collaboration) to improve laboratory learning outcomes. The integrated system developed here makes use of an open source platform and a widely used remote lab sharing platform and can therefore contribute to the such future research. Additionally, the lessons learnt from the implementation, such as the limitation for animation support in Open Wonderland, are valuable for further work in the area.

7.1.3 What experiment would be suitable to test students' ability to identify the strengths and limitations of models as a predictor of real-world behaviour?

Discussed in detail: Section 4.6.3.

Summary: The iLabs based remote radiation laboratory was selected (over the LabShare hydroelectric energy and inclined plane laboratories) due to its availability, the access to existing learning activities, the suitability of the underlying inverse square model and the limited inherent domain context.

Further Conclusions: The domain context for this laboratory was successfully designed, the laboratory assessment developed and the lab integrated into the virtual world illustrating the suitability of the selection of the remote radiation lab for this research.

While the selection of the laboratory was suitable in terms of the potential to improve and test the learning outcome, taken together with the sample used in this research it may have led to a bias in research results. In selecting the Health Physics and Radiation Biology student cohort, the participants had all previously had exposure to a laboratory experiment which investigated the inverse square model in a different laboratory set-up. While initially considered advantageous, this prior exposure to a similar model may have had an effect on the targeted learning outcome. The previous lab contributed to participants' prior knowledge and, as well as helping to ensure they started with similar levels of knowledge of the model, it would have contributed to their context generating processes. This was discussed briefly in response to another research question (section 6.4.1) and is addressed again in more detail in section 7.2.1.

7.1.4 What defines domain context?

Discussed in detail: Section 4.6.1.

Summary: This research looks specifically at the way information presented to contextualise an activity may influence how students learn about models. For that reason, the term *domain context* was defined as those elements of the context that relate to the content of the learning activity, as opposed to *situational context* which is those elements that are independent of the learning activity (such as a student's prior learning, physical environment etc.).

Further Conclusions: The definition of domain context has framed the discussion regarding contextualised laboratories in this research and provides a contribution to further discussions concerning context and learning (see for example Machet and Lowe (in press)).

The results of the research indicate that the previous inverse square model experiment to which participants were exposed may have had an influence on the context available to all the students. This suggests that domain context does not include only those contextual elements presented at the time of the learning activity. The results of this research highlight the fact that domain context should also be considered to include content-specific information presented to students in their surroundings and in other learning activities, and that the link between context and content does not require the contextual elements to be presented at the same time, or within the same space, as the content.

7.1.5 How could contextual information aid students in being able to identify the strengths and limitations of models as predictors of real-world behaviour?

Discussed in detail: Section 4.6.2.

Summary: Context can affect learning by helping students understand relationships, link new information to existing knowledge, identify the key concepts under study and transfer knowledge from one domain to another. This understanding has contributed to the hypothesis that contextualising a laboratory activity can help students understand the complex relationship between models, the laboratory and the real world which results from the nature of models and laboratories as partial representations of the real world. An improved understanding, it is argued, will affect students' ability to identify the strengths and limitations of models as predictors of real-world behaviour.

Further Conclusions: This question is central to the research hypothesis. While the argument was made and supported for how context can aid students, the results indicate that in the case investigated here, the context did *not* help participants identify the strengths and limitations of the inverse square law model as a predictor of real-world behaviour. Identifying the reasons for this and its implications will contribute knowledge to the fields of laboratory learning outcomes and contextualised learning.

Any application of a model in the real world is done within an environment that will contain domain context. Through the addition of domain context to the laboratory, this research aimed to create cognitive bridges that would prompt students' reasoning by linking to existing knowledge of the real world or highlighting the key concepts under study. It may be that the cognitive bridges as designed were not effective in creating the links between the treatment participants' existing knowledge and new knowledge, or in fulfilling the functions of context (particularisation or coherence) any more than existing domain and situational context had done for the control group. This concept is related to the fact that all participants had access to a laboratory investigating the inverse square law, and real world contextual elements within the laboratory room. It is explored further in section 7.2.1.

An alternative explanation is that the link between context, the laboratory and the real world in this case cannot be explained principally by the interactions hypothesised here, and that other factors are affecting students' understanding. These factors may be found in the nature of the laboratory activity or the domain context added, or in the cognitive processes that are involved when context influences reasoning and understanding. Once again, section 7.2 discusses in more detail influences such as the timing of the learning and assessment, the strength of the contextual narrative and the complexity of understanding models and of reasoning as a result of context.

7.1.6 Can general guidelines be proposed for the type of contextual information that may be presented?

Discussed in detail: Section 4.6.4.

Summary: Having investigated the literature, no guidelines could be found for the design of domain context for a laboratory. A contextual framework was developed that combined the central ideas on domain context to provide guidance on what elements would best support the learning objective. The framework defined the following steps: identifying the learning objectives and existing domain context elements; determining the function of each domain context element; determining the type of information each element should include; combining these into a sensible narrative; and analysing the resulting design. The context framework can be sensibly applied to existing laboratories to analyse the domain context they contain. Additionally, the framework can inform the design of context for new labs as has been done for this experiment.

Further Conclusions: Looking at the framework critically in light of the research results gives insight into how it should be applied. Firstly, as shown here, while the framework can be applied to any laboratory, it will not always yield useful outcomes as the framework does not include any determination of whether the laboratory and learning outcome selected would benefit from contextualisation.

Using the framework as a design tool has resulted in a focus on the function of context. This was very useful in selecting, from the very many possibilities, which aspects of the real world would be suitable as context for this experiment. The framework does not *prescribe* a context design, but rather guides its development and has been shown to be very flexible in this research by presenting a number of context options and accommodating changes required by implementation limitations. Future research could be done into using the framework as an analysis tool for exploring the contextualisation of existing labs.

One aspect of the framework that may benefit from more attention is the presentation of context. The framework suggests a narrative as a method for presenting contextual elements in a way that makes sense to students, however there are no indications of what qualifies as a ‘good’ narrative and how students are expected to experience or interact with it. This is explored further in section 7.2.2.

7.1.7 Given the laboratory selected, what kind of contextual information should be added?

Discussed in detail: Section 4.6.5.

Summary: Applying the contextual framework to the remote radiation laboratory resulted in a design that included the radiation lab within a Research Complex that comprised an acoustics room, light laboratory, X-ray laboratory, radiation research laboratory and atomic research laboratory with scaled animated model of a decaying atom. The design also informed that the virtual world contain background elements indicating radiation sources and that students' avatar carry a simulated Geiger counter.

Further Conclusions: The design and implementation of the context for this laboratory demonstrated the feasibility of adding context and the planned Research Complex, with a few limitations, was used to contextualise the remote radiation laboratory.

In light of the results which showed no improvement in the targeted learning outcome, it is necessary to look at the final experiment to see if there are insights about the included contextual information that can be gained from the research. Much of the context involved real world examples of absorbers, radiation sources and other examples of where the inverse square law is applicable in the real world. These were designed to link to existing knowledge students have about the real world, and stimulate their reasoning. Each of these elements were selected as they are common and were likely to be familiar to students from their real world experience and it was posited that awareness of them within the laboratory activity may improve the link to the real world. However, from the participants' desks in the laboratory, many of these contextual elements could be observed in the real world (sunlight, sound from other students, radiation sources such as mobile phones and computers, etc.). The real world examples were available to both the treatment and control groups. Including the context explicitly in the laboratory activity may not have aided participants to make the connections any more than observing the real world phenomena did. This is related to how students perceive the context (further discussion in section 7.2.2) and learn from it (investigated further in sections 7.2.1).

One of the designed elements of context that could not be implemented was the scaled-up model of atomic decay. This would contain contextual information not available in daily life and be less like students' real world experiences (due to the scale of radioactive decay). Including an element that could not be perceived by the control group elsewhere, would have perhaps resulted in a larger effect on learning outcomes.

7.1.8 How should the contextual information be presented?

Discussed in detail: Section 4.6.6.

Summary: A virtual world allows the presentation of context for a remote laboratory activity. Importantly, the context should be incorporated into a narrative that is meaningful to students. For this research, the narrative is the students' trip through a virtual Research Complex with real world like elements.

Further Conclusions: The presentation of context has been discussed from the technical point of view in section 7.1.1. It can also be considered from the perspective of the strength of the narrative. The simple narrative of navigating through the Research Complex that included the designed contextual elements, was designed for students to be 'aware' of the context rather than compel interaction or engagement with the context elements. The research results indicate that the presentation of the context this way was not successful in changing the learning outcome, at least in this example.

There is no measure in this research of the level of awareness of the contextual elements or the engagement with this narrative. It can be argued that more than simply awareness of contextual elements is required in order for the contextual elements (especially those that may be perceived ordinarily in the real world) to be linked in students' reasoning to the laboratory activity itself. Section 7.2.2 provides a discussion on the impact of awareness as opposed to interactive engagement.

Future work in the area may look to measure the difference in learning outcomes between activities conducted in a context rich environment that requires no active engagement with the contextual elements, and one that does require some sort of interaction that facilitates a 'deeper' engagement.

7.1.9 What constraints does the technical implementation of the system impose on the laboratory activity and its learning outcomes?

Discussed in detail: Section 5.6.3.

Summary: The technical implementation did impose some constraints on the design of the context and therefore possibly on the learning outcomes. The context was designed according to the newly developed context framework with an expectation of what could reasonably be implemented in Open Wonderland, however, during the development and implementation phases it was found that the animated atomic decay model and the simulated Geiger counter could not be implemented within the scope of this research. Additionally, the sound from the microphone was left out of the final implementation because differences in volume would not be heard within the laboratory class environment.

Further Conclusions: The inability to implement all the designed contextual elements meant that the context did not address one of the weaknesses of the inverse square model, namely that radioactive decay is a stochastic process (rather than the determinative process described by the inverse square model). It also limited the degree to which other limitations were addressed, specifically the presence of background radiation and absorption highlighted by the simulated Geiger counter.

Another effect of these limitations was that the three-dimensional affordance of the virtual world was not used to its full potential, possibly weakening the narrative provided by the contextual elements in the virtual world. The narrative element of contextualised learning enables engagement for students and provides a meaningful situation in which the learning occurs.

The failure to address all the strengths and limitations as designed through the contextual framework, or to maximise the impact of the narrative within which the context is experienced, may have had an effect on the size of any changes in learning outcomes that could be expected to result from the contextualisation of the lab activity. Considering that the literature has emphasised that often educational research shows small effects, this could mask potential learning improvements.

The effect of the narrative on learning outcomes is discussed further in section 7.2.2.

7.1.10 What factors resulting from the technical implementation can affect the learning outcomes of the laboratory?

Discussed in detail: Section 5.6.4.

Summary: The design and development process adopted in this research for developing the integrated laboratory environment meant that the effects of the technical implementation were considered in the requirement definition stage to ensure the validity of the results. The factors deemed most likely to influence the learning outcomes were: the ability for the designed context to be implemented; the establishment and maintenance of students' perceptions of the equipment as real; the effect of the novelty of the integrated system; and the potential distraction it provided. Each of these was controlled as far as practically feasible in the implementation and execution of the laboratory.

Further Conclusions: As the research results showed no statistically significant differences between the control group and the treatment groups it is important to look at whether any of these influencing factors could have affected or masked learning outcome improvements.

Within the limitations described and discussed in section 5.6.3, the context was effectively created for the virtual world and arguably perceived to some degree by the participants in the treatment group. As far as the reality of the equipment is concerned, observations lead to the conclusion that participants understood the nature of the lab as real: all groups used the camera panel within the world and there were no reports of questions regarding the reality of the lab equipment.

Navigating through the virtual world did not provide a barrier to completing the laboratory activity. The results from the research questionnaire indicate that most participants enjoyed completing the laboratory within the virtual world, and while some participants who had the contextualised virtual world indicated that they found navigating through the world more difficult, the majority of all participants reported a positive responses to its' ease of use. Observation of the participants supported this with only two groups (one each from the treatment and control groups) requiring assistance to execute the laboratory.

Overall, participants did not perceive the contextual elements as distracting. It was the participants in the control group who were more likely to report that the virtual world was distracting, presumably because they could see no 'additional benefit' to the empty virtual world. This however, measures only their perception (which is not equivalent to learning outcomes as shown in the literature (Lindsay & Good, 2005) and in this study (see section 6.3.5.3)). There still exists the possibility that the context provided a distraction that attenuated learning outcome improvements, however it is believed this is unlikely as participants were not required to engage in any way with the context (a possible explanation for the lack of improvement in learning outcomes).

The nature of the novel implementation meant that there is the possibility that there was an influence on results due to the novelty effect (whereby performance can improve when a new technology is introduced due to the novelty of using the technology rather in response to the treatment). While both the treatment and control groups were presented with the same activity as far as possible, the integrated system was new for all participants as a lab environment for this course and it cannot be discounted that small effects in learning outcome differences could be masked by an improvement in both groups.

7.1.11 How will influencing factors be controlled and/or accounted for in the empirical research study and research conclusions?

Discussed in detail: Section 6.4.1.

Summary: Given the influencing factors identified through the research and development design, steps were taken to control for these influences, and where necessary, consider their implications in drawing conclusions from the research. The steps taken included: common instructions and motivational drivers to all participants; emphasis on the reality of the laboratory equipment using live video; measurements of participants' perceptions and attitudes; and observation of any difficulties and accounting for copying between group members.

While many of the factors could satisfactorily be accounted for, some do present a threat to internal and external validity. Most significantly the novelty effect (discussed in section 7.1.10), the Hawthorne effect, history effect and the implications of the factors not measured or accounted for such as participants' abilities and learning preferences.

Further Conclusions: Having found that there are circumstances where a contextualised laboratory does not affect the targeted learning outcome, the other influencing factors must be considered closely for their influence.

As well as the possibility that the novelty effect may have masked improvements, the Hawthorne effect (whereby performance improves due to the fact that participants know they are being observed) may similarly have had an effect across both groups. This is unavoidable due to the ethics requirements for the study and could potentially have masked small learning improvements.

What is considered to have had more of an impact, however, is the 'history' effect as presented in this research: that all students completing this laboratory had previously had exposure to the inverse square model in a light intensity laboratory activity. While it was expected that this would ensure that all participants within this study had a similar level of prior knowledge, it could be that this existing knowledge meant that all participants had 'context generating' information available to them (in line with Kokinov's (1999) approach to context as a state of mind). This threat to internal validity and its implications for knowledge in the field are discussed in more detail in section 7.2.1.

Additionally, this prior exposure may mean that the potential to improve participants' understanding regarding this particular model was limited as it had been developed already. This affects the external validity of the research and future work could look at whether there is any difference in learning outcomes when a new model is presented to students.

Information on aspects that affect learning such as student demographics, learning preferences and abilities did not form part of this research project. While they were out of the scope for this research and compensated for as far as possible with the random assignment of lab groups to either the contextualised or non-contextualised world, their influence cannot be discounted when deciding whether these results can be generalised. Specifically, the control groups and treatment groups were not 'matched' in these regards and the lab group members were not randomly assigned. It is suggested that future work in the area may look at the group composition and determine whether these factors may have had an effect on the results.

7.1.12 How can improvements in students' ability to identify the strengths and limitations of models as a predictor of real-world behaviour be measured?

Discussed in detail: Section 6.4.2.

Summary: Improvements in understanding were measured with the use of carefully considered pretest and posttests which focused on the learning outcome. The pretest consisted of TRUE/FALSE questions and the posttest included the laboratory activity tasks, a repeat of the pretest questions and longer, more open response questions.

Further Conclusions: In light of the findings, it is important to clarify whether the targeted learning outcome was measured. In the assessment design, consideration was given to best practices in research design, measurement of learning outcomes in laboratories and for remote labs in particular (see sections 3.3, 3.3.2 and 2.1.5.1).

At a high level, the TRUE/FALSE questions specifically test the identification of the strengths and limitations of the model as predictors of real world behaviours. The second set of TRUE/FALSE questions, for example, require students to identify whether other described phenomena follow the inverse square law (an identified strength of the model). As expected due to their previous light source laboratory, most participants could identify that the law applies to light from the sun (78 and 79 correct responses out of 80 in the pretest and the posttest respectively, see Appendix I). This indicates an understanding of the question and its' validity in testing students ability to identify one of the strengths of the model.

The measurements, however, were specific to this research's implementation of the laboratory, and therefore there is no baseline measurement for determining how well it measures the targeted learning outcome. There are other assessments that could be carried out, such as including an assessment item for this learning objective in the course exam, however that was not possible in this research study and it would introduce the problem of controlling for the effect of other influences on student learning in the period between the lab and examination. Thornton (1998) highlights the usefulness of a concept inventory (a large bank of research based multiple choice questions testing a concept) for topics such as Newton's Laws of Motion. Potentially a model which has an associated concept inventory can be used in future work to more reliably assess students' improvements in understanding.

A further consideration is the timing of the testing. Both the pretest and posttest were given to participants within the two hour laboratory session. It is possible that, with little time for reflection, the effects of the intervention were not apparent in the testing. The lack of reflection time is a limitation to the study results and its implications are discussed further in section 7.2.3.

7.1.13 How will it be determined whether students' understanding has improved after completing the laboratory?

Discussed previously: Section 6.4.3.

Summary: The difference in pretest and posttest scores was used as an indication of improved understanding. The statistical significance of the difference between the treatment and control groups was determined using a two-tailed t test on the means of the paired pretest and posttest differences. With a confidence interval of 95% and a power of 0.8, the null hypothesis could not be rejected.

Further Conclusions: While this analysis was suitable for this research, future work could analyse these results for variations that may correlate to other factors such as gender or students' abilities. This would require different (covariant) statistical treatment.

7.1.14 Does students' understanding of models improve with the setting of the remote laboratory in a context-rich virtual world over the same laboratory in a non-contextualised world setting?

Discussed previously: Section 6.4.4.

Summary: There is a case where adding domain context to a laboratory, despite expectations, does not result in any difference in the learning outcome concerning students' understanding of models.

Further Conclusions: Experience and knowledge into the effect of the contextualisation of laboratories has been advanced. This result represents a contribution to the fields of laboratory learning outcomes and the effect of context on learning. The result will contribute to the future design of laboratories and it provides avenues for further research in the area of laboratory learning outcomes.

Section 7.2 discusses the implications of these findings. The discussion will be used to contribute to the final research question on identifying future areas of research which is detailed as part of the conclusion for the thesis in section 8.4

7.2 Discussion

The results described in Chapter 6 show that providing students who are undertaking a laboratory activity with contextual information did not (at least in this specific case) have a statistically significant effect on their understanding of models and their ability to identify models' strengths and limitations as predictors of real-world behaviour.

While it has been argued that providing domain context to a laboratory activity can be expected to affect learning outcomes, this result suggests that the interaction between the context and measured learning outcome is not as direct or certain as might have been expected from the analysis of prior research. In order to understand the implication of the result and explain the lack of a significant effect, it is necessary to look back at the literature that describes the learning in sciences, the effect of context on learning in general, and learning in laboratories in particular.

The discussion presented here considers the cognitive processes that are involved when context influences reasoning and understanding, and the nature of the laboratory activity or the domain context added. The conclusions are mapped back to background theory which is re-evaluated in light of new knowledge.

7.2.1 Kokinov's Ideas of Context

From the literature, Kokinov (1999) considered context as a state of mind (rather than an environment) that is the result of the interaction of three processes: perceiving the environment; accessing and reconstructing memory; and reasoning. The context comprises all entities involved in these processes that are prioritised by the mind at a particular moment.

This research has looked at manipulating the perception (through the act of physically presenting contextual elements) and using these as a trigger for the retrieval of certain memory elements and hence to change the state of mind and thereby induce reasoning to create a better understanding of the underlying concept. This research had not explored in the initial analysis, however, what else is presented to the participants. It may well be that the complex interaction between these processes means that although those in the control group are not presented with the input to their perception, they can construct a similar context to those in the treatment group using their memory and reasoning. Additionally, as many of the elements displayed to the treatment group are present in the real world, they are potentially available to the context generating processes of all students. In this case there is no way to measure the context that each student has created for themselves.

All participants in the group had already completed a lab activity on the inverse square law and learnt the concept in lectures. This was seen as an advantage as it meant there was more certainty that the participants (who had different levels of physics education coming into the course) had similar prior knowledge of the model being investigated. It can be argued however, in light of this interpretation of ‘context as a state of mind’, that this acted to confound the research results. With prior exposure to the model under investigation, there would have been memory elements and a level of reasoning available all the participants. The prior knowledge may mean that the new context presented to the treatment group did not contain sufficient new information to make the treatment groups’ context during the lab activity significantly different to that produced by the control group.

Contributing to this may be the effect of the pretest used. Norman and Streiner (2003) suggests that a pretest may indicate the purpose of the intervention to study participants and along these lines, it is possible that the questions in the pretest acted to prompt the memory-induced and reasoning-induced context generating processes for participants in both groups.

Future research may look to repeat a similar experiment to that in this research, but one which measures or controls for participants’ prior exposure to the model under study. Such research would require careful selection of the model and student cohort, possibly selecting high school students being introduced to a concept for the first time.

7.2.2 Strength of the Narrative: Interaction vs Awareness

The context framework developed in this research has proposed that contextual elements be included within a narrative. A fitting narrative has been considered to be one in which the contextual elements are combined in such a way that they make sense to the student experiencing them. There is no measure of the 'strength' or 'suitability' for the narrative in this research, however student can be considered to be either passively 'aware' of contextual elements, or actively 'engaged' with them.

The literature on contextualised learning covers a wide range of subjects and circumstances, and much of it refers to situational context, as has been defined in this research, or a combination of domain and situational context. In that research, there is little discussion of 'awareness' of context by the participants. That is, context can influence learning, retrieval and transfer of knowledge without conscious awareness of the contextual elements (Balsam & Tomie, 2014). This is especially true of situational context which may involve elements that students cannot perceive within the learning activity.

However, when the literature on contextualising laboratories is considered, there is far more discussion of how students perceive the context and engage with the contextual elements and the narrative that these elements construct. This is to be expected to some degree due the nature of laboratories as active learning environments where students are often required to experiment, observe and consider their findings. Examples of contextualised laboratories in the literature look at questions as context-generating prompts (Demetriadis et al., 2008), problem solving in contextualised settings (Barab et al., 2007; Winn et al., 2002), or 'real-life' scenarios (Back et al., 2010), all of which illustrate a level of interaction between the learner and the context being presented.

The research behind the new context framework does not require that students interact with the contextual elements being developed, but their level of awareness may have had an effect on the outcomes if it is considered that many of the 'real world like' contextual elements included in the laboratory environment were available to the control group should they be aware of their surroundings (such as the presence of other radiation sources from computers, phones, and sunlight). Although linking these contextual elements directly to the laboratory through the use of the virtual Research Complex narrative was expected to ensure that participants in the treatment group perceived these as being linked to the laboratory content, it may not have been achieved any more than was available to the control group.

It can be argued that the complexity of how students learn about models and the information required for changing the understanding of their strengths and limitations, means that presenting contextual information is, on its own, insufficient for making significant conceptual changes across a cohort of students. It may be that in a laboratory setting, a level of interaction or engagement with the domain context is required in order to create a measurable effect on learning outcomes. There is support for this proposition in the literature. The PhET project (simulations for science learning), concludes in Adams et al. (2008) that ‘simulations that suitably incorporate interactivity, animation, and context can provide a powerful learning environment’ (p. 576). Barab et al., 2007 research on embedded, embodied and abstracted formalisms (as a description of the relationship between context and content) contributed to the contextual framework developed in this research. In their approach, they propose that, through participating in a laboratory activity, formalisms are contextualised for students, and with reflection, abstracted. While this research project incorporated context for the treatment group, there was limited interaction with the new contextual elements. The interactions involved in the laboratory activity were limited to executing the remote lab (which was the same for both groups) and this may have had an effect on contextualising the content for participants.

In this vein the possible effects of the limitations on the creation of the context should be considered. The inability to create a three-dimensional animation of radioactive decay, a responsive Geiger counter or to include the sound from the microphone meant that the contextual elements presented to the treatment group did not take full advantage of the affordances of virtual worlds to present dynamic, three-dimensional information. The effect of these limitations was possibly to weaken the narrative presented to participants and engage them less in the contextual elements and the laboratory activity.

The responses from the research questionnaire indicate that the treatment group were aware of the context to some degree, for example participants in the treatment group were more likely to report that they felt they had learnt from the laboratory because it was set in the virtual world. The research however, did not measure the degree to which participants explored the Research Complex. Future work could look at measuring student awareness or interaction with the context to test whether it is being perceived as expected.

7.2.3 How important is timing?

The context framework used in this research drew together research by Ausubel, Novak, van Oers, Gilbert and Barab et al. and other. The laboratory used in the research presented context developed from the framework within the two hour laboratory session. The presentation of the context, the narrative and the testing were contemporaneous with the laboratory activity.

The cognitive bridge that Novak (1976) proposes for linking into student’s existing knowledge is based on Ausubel’s (1960) advanced organisers. These advanced organisers present more general or abstract information to prime the student to link new knowledge to existing knowledge.

The temporal aspect of preparation of the learning environment is missing in the laboratory activity in this research. It may be hypothesised that this temporal aspect is more significant than has been assumed.

Examples in the literature of contextualised learning in virtual worlds, such as the virtual mirror of the chocolate factory (Back et al., 2010), learning in the virtual replica of the Coogee Energy's methanol plant (Norton et al., 2008), and Circuit WarZ game based learning for electrical engineering (Callaghan et al., 2013), all display the same co-incident context and content features of the laboratory. However, their research points to improved user engagement as an effect of the environment, rather than a better understanding of how the content links to the real world.

The experiments by Godden and Baddeley (1975) which show the effect of contextualised learning, measure memory recall of words learnt in different environments. Memory recall has a temporal aspect that is not explored in this research study. It may be that the effect of the contextualised learning on understanding requires reflection or has an effect on later transfer of the knowledge to a new context.

In support of this, much of the literature on scaffolding learning includes prompts for students to encourage reflection or suggests time for reflection in learning activities (Demetriadis et al., 2008; Hofstein & Lunetta, 2004). The literature review also describes reflection as an important component in the learning from laboratories: Barab et al. (2007) suggest reflection is required to 'abstract' a formalism; Jenkins and Jona and Adsit cite 'ongoing discussion and reflection' as a fundamental principle for effective laboratories as does Lee et al. (2008) for physics simulations.

The necessity for students to have time to reflect on learning activities has also been identified in the literature on laboratory learning (Hofstein & Mamlok-Naaman, 2007; Jona & Adsit, 2008). Hofstein and Lunetta (2004) suggest that learning from laboratories is a complex process and commented on the lack of opportunity for 'metacognitive' activities in laboratories: students need the time and opportunities for feedback, interaction and reflection to best learn from lab activities.

This suggests a future avenue for research. Whilst this research reported on immediate learning outcomes, it may be worthwhile exploring whether contextual information presented to students who are then given time for reflection, results in better long-term understanding of recall of the strengths and limitations of the model as a predictor of real-world behaviour.

What these results and the discussion have highlighted, is that the provision of context alone (even when carefully designed) is not always sufficient to improve students' understanding of the relationship between models, laboratories and the real world. The process of learning from context is subject to other factors that affect outcomes.

It may be that any or all of these factors played a role in influencing the research results. They are linked to some degree in that, if the narrative can be adapted to ensure that students interact with the context and are given opportunity to reflect on the activity before testing is done, the results on students' context generating processes may be significant enough to differentiate their learning from those not given the domain context stimulus (regardless of the prior exposure to the model).

7.3 Chapter Summary

This chapter has presented a discussion of the research findings. In summary:

- The research questions were addressed by summarising previous findings and adding further conclusions drawn from the results of the empirical study.
- The chapter explored possible explanations for the research finding that the null hypothesis could not be rejected.
- All students create context as a 'state of mind' based on perception, memory and reasoning processes. As all particpants in the study had previously been exposed to the inverse square model in a light laboratory, and been presented the pretest questions which may prompt memory and reasoning processes, it is possible that the additional context generating effect of the contextual elements in the laboratory were insufficient to make a difference to the context generated by these treatment group participants.
- The context for this research did not include interactive elements and while it is believed participants were aware of the context, there is the possibility that this was insufficient to change learning outcomes. It may be that the effect of context in laboratory requires a higher level of interaction with that context in order to achieve learning outcome improvements.
- This research provided little time for participants to reflect on their activities. The literature indicates that reflection time may be an important factor when contextualising learning.

Chapter 8

Conclusions, Contributions and Future Work

This concluding chapter summarises the research conducted for this PhD and the conclusions that have been drawn from the research process and results. The chapter highlights the contributions to knowledge made by the research and situates them within the current body of knowledge. The limitations to the research are outlined and future work in the area is proposed based on this research.

8.1 Research Summary

This research developed from a recognition that there is scope to improve learning outcomes in laboratories, and that rapidly changing technologies (such as remote laboratories and virtual worlds) present an opportunity to achieve these learning improvements new ways. It is the problem of how to improve learning outcomes for laboratories that this research aimed to address.

In order to understand where a contribution could be made in the field, a thorough literature review was conducted. The literature review looked into research on learning in the sciences in general and laboratories in particular. Focus was placed on one identified learning outcome of laboratories: the understanding of models and students' ability to identify their strengths and limitations as predictors of real-world behaviour. The review explored the literature on the roles that laboratories, models and context play in learning, and the relationship between these concepts. This led to the identification of a gap in current knowledge: it is not known whether adding domain-specific contextual information to a laboratory can improve students' ability to identify the strengths and limitations of theoretical models as predictors of real-world behaviours.

To explore this gap in knowledge, remote laboratories and virtual worlds were investigated to determine whether they could provide a suitable platform for investigating the effect of contextualising laboratories. Remote laboratories were found to be pedagogically sound as a laboratory mode for achieving this learning outcome. Virtual worlds (while their contribution to learning outcomes is under debate) have the proven ability to create a context for learning and so make them a suitable tool for this research. The following hypothesis was proposed for the research:

> *Embedding a remote laboratory within a virtual world that presents domain context can improve students' ability to identify the strengths and limitations of theoretical models as predictors of real-world behaviours, over the ability developed using the same laboratory in a non-contextualised setting.*

The hypothesis was deconstructed into 15 research questions to be answered by the research. In order to address these questions, four phases were identified: a synthesis of existing literature in the field, the design of a suitable context for the laboratory, the design and development of integrated virtual world and remote laboratory system and an empirical investigation to test the hypothesis.

A number of remote laboratories and virtual worlds were compared and an iLabs based remote radiation laboratory investigating the inverse square law along with the Open Wonderland virtual world were selected. Design solutions were considered and the best balance between system requirements, development efforts and practical and technical limitations resulted in the partial integration of iLabs functionality into the Open Wonderland virtual world. As well as providing a test platform for the research, the process of design and development answered questions about the extent to which a laboratory can be enhanced with context, and provided a foundation for further integration of iLabs remote labs into Open Wonderland.

The literature review provided insight into the topic of contextualisation in laboratories but it was found that there were no guidelines for what domain context should be added to an activity to potentially improve learning outcomes for laboratories. The synthesis of the literature guided the design of the domain context for this laboratory and it was found that this guided context framework could be used for the analysis of existing context in labs, as well as for the design of new context, so defining a new context framework. The designed context was added to the virtual world in the form of a Research Complex showcasing a number of phenomena to which the inverse square law for intensity at a distance applies, as well as real-world like surroundings which included contextual elements that related to the strengths and limitations of the model (for example background radiation and radiation absorbers). Some limitations in the implementation meant that not all the designed contextual elements could be included in the final lab.

Having developed the testing platform, an empirical study was completed with a cohort of undergraduate radiography students who are required to understand the inverse square law as part of a course on Health Physics and Radiation. The results from the empirical study showed that there was no statistically significant differences between the control group and the treatment groups and the null hypothesis could not be rejected from the evidence in this study. The research, therefore has shown that there are cases where contextualising a laboratory activity will not have an effect on students' ability to identify the strengths and limitations of models as predictors of real-world behaviour.

The implications of these results were analysed with reference to the existing literature. The results show that there may be other (masking or attenuating) effects that play a role when students are presented with a contextualised laboratory. These have been proposed to be: the effect of the level of awareness of the domain context elements that is required to change students concepts within a laboratory activity; the effect that previous exposure to the model in another laboratory may have had on the context generating processes for students; and the timing of the testing which left little scope for reflection.

In conclusion, this research has successfully tested the hypothesis and addressed each of the research questions posed. The research has contributed to knowledge to the field of laboratory learning outcomes, beginning with the clarification of the relationship between models, laboratories and the real world and developing the hypothesis that domain context may help to strengthen students understanding of this relationship. While these concepts are drawn from the literature, the definition of domain context and the explicit description of the model-laboratory-real world relationship serves to clarify future discussion and research in the area. Additionally this research has provided a context framework whose usefulness in analysing and designing domain context for laboratories has been illustrated. This framework provides a basis for future work in the area of contextualising laboratories. A contribution has also been made in the development of the integrated virtual world and remote laboratory which can be re-used as a whole (or in parts such as the Service Broker API) to further investigate laboratory learning outcomes and the potential that virtual world affordances provide to improve laboratory learning outcomes.

The contribution to knowledge has been primarily in the demonstration that providing contextual information to a laboratory does not always provide significant improvements to the learning outcome concerning models, and therefore, in providing such context, the effort involved and the possible effect of other context generating information must be considered.

8.2 Contributions to Knowledge

The objective of this research was primarily to contribute new knowledge to the field of laboratory learning outcomes. In completing the project, this has been achieved along with the contribution of re-usable laboratory environment, a useful framework for analysing and designing domain context in laboratories, and a number of definitions and clarification of concepts that can be used to frame and direct future discussions.

8.2.1 The Effect of Contextualising Laboratories

Most significantly, the results of this research contribute to the existing knowledge on the improvement of laboratory learning outcomes, the broad problem that this research aimed to address. More specifically, this research delivers new information on the effects that contextualising laboratory activities have on the learning outcome concerning the understanding of models.

It was found that there are cases where adding domain context to a laboratory activity does not improve students' ability to identify the strengths and limitations of a model as a predictor of real-world behaviour.

8.2.1.1 Implications

There is a significant amount of time and money devoted to laboratory activities, and maximising their value to educators and students may have a large effect. This involves ensuring that laboratories effectively meet their learning objectives. Only relatively recently have the (now widely accepted) ABET laboratory specific learning outcome been described (Feisel et al., 2002). As a result there is much scope to investigate these learning outcomes and investigate possible methods to improve them. In addition, new technologies are being adopted and applied in learning environments, presenting potential benefits, and possible drawbacks, to learning outcomes. Their use, and the effort involved in applying new technologies, should be justified by evidence of improvements in outcomes which requires research studies such as this.

Concerning the learning outcome of models in particular, students who can develop a good understanding of models and modelling can better transfer the knowledge they learn to new domains, they learn to behave as ‘experts’ do rather than ‘novices’. The effect of this applies not only to the specific laboratory or model under study, but once they have this understanding of what models are and how to use them, it may improve how they interpret and apply all models they encounter (as they change from a ‘novice’ view to an ‘expert’ view).

The lack of a significant effect resulting from adding the domain context to a laboratory shown in this research indicates initially, that while it is technically feasible and seemingly enjoyable to students to conduct a laboratory in a contextualised virtual world, the effort may not be valuable in terms of improving the model learning outcome. However, the conclusions drawn also indicate that the lack of effect may be due to the presence of other context generating information that was available to all students (such as the previous inverse square model laboratory). The implication is that future research should carefully consider the choice of the model under investigation for possible alternate sources of context, and the time and money spent must be weighed up in light of the evidence that there are cases where context will not make a difference.

These conclusions are in line with the conclusions of Winn et al. (2002) who indicated in their research that the cost of developing (in their case) an immersive environment for teaching was justified only after careful consideration of the concept being taught.

8.2.2 Context Framework

Synthesis of the literature the topic of contextualisation in learning led to the definition of a framework that was used to inform the selection of the domain context for the remote radiation lab (detailed in section 4.3). In addition, the hydroelectric energy laboratory was used as a case study to indicate how the framework is useful in analysing existing context.

This context framework constitutes a contribution to the field of contextualised learning in laboratories as it provides a guide that links the context of a laboratory activity to the content under study in a novel way that covers the function of the contextual elements, the information they convey and the nature of their presentation.

8.2.2.1 Implications

The literature provides examples of contextualised laboratory activities (in fact, the laboratory equipment itself often provides domain context). However, in many cases this domain context is incidental to the design of the laboratory and its effects are not investigated. This research investigated the effect of domain context on one learning outcome for laboratories but there is the potential that context can have an effect on other outcomes - such as students' perceptions of the laboratory work (which has been indicated to some degree by the responses from the research questionnaire). The context framework here provides a mechanism for describing the domain context present in laboratories and can be used to frame future discussions on other effects that context (or lack there-of) may have on learning outcomes.

The context framework will be useful in exploring further the conclusions drawn from the results of this research, specifically that it is possible that students need to interact more with context in order for an effect to be significant. It is possible that the context framework should be augmented with a measure of awareness or interactivity. Using the framework to analyse context in existing laboratories can provide a basis for comparing different laboratories and gauging the effect of the context in term of how well they address the factors described by the framework.

8.2.3 Re-usable Integrated Virtual World and Remote Laboratory Solution

The design and development of the system has delivered a re-usable interface between iLabs remote laboratories and the Open Wonderland virtual world. This interface is new and available for further lab integration for research or teaching (detailed in section 5.2.2).

8.2.3.1 Implications

As well as illustrating the feasibility of this integration solution, the re-useable component will mean that any future integration of an iLabs laboratory into Open Wonderland can be done with less time and effort. This is particularly significant as it has been identified that future investigations must consider time and effort in light of the lack of significant effect found in this research.

8.2.4 Clarifying Relationships Between Context, Models, Laboratories and the Real World

This research has made explicit the relationship between context, models, laboratories and the real world. While recognition of these relationships are not new and have been drawn from the literature, the distinct expression given to them here has contributed to clarifying these relationships and provides a mechanism for discussing context and models in a laboratory environment. Specifically, the following concepts have been clarified and defined:

- *Laboratory as a proxy for reality.* As it is often logistically difficult (and sometimes impossible) to engage with reality and its complexity and scale, the laboratory is used as a more accessible version of the real world that is more easily manipulated and controlled, and hence can be used to investigate models. In conducting the laboratory activity students are developing an understanding of the relationship between the theoretical model being investigated and the experiment. The expectation is that this understanding can then be applied to the real world that the model describes and the experiment represents. Laboratory activities are tools that allow us to investigate a theoretical model and how it relates to reality, including the strengths and limitations of that model in predicting real-world behaviour. These strengths and limitations exist due the nature of models and laboratories as partial representations of the real world.
- *Domain and situational context.* These concepts were defined to distinguish types of context referred to in the literature. Situational context refers to contextual information that is independent of the learning content such as the physical, personal, social or technological environment in which the experiment is being conducted. Domain context is specific to the task and relates to the content of the learning activity. These elements relate to the specific laboratory equipment, the underlying model being investigated, the learning outcomes being targeted and the method of executing and assessing the lab activity.

8.3 Limitations of the Research

This thesis describes an in-depth study into the contextualisation of laboratory activities and the possible effect on learning outcomes, however it is acknowledged that the research conducted here covers only a small aspect of the field. The boundaries of the gap in knowledge, the scope of the study, the methodological restrictions and the practical realities of implementation and execution of the research have all imposed limitations on the study and the ability to generalise the results obtained. These limitations have been considered throughout the design, implementation, testing and analysis and form part of the research conclusions. They are summarised here.

In terms of the scope of this research, the bounds of the gap in knowledge described in section 2.5, define some of the limits of this research. The research looks at one particular laboratory learning outcome (that concerning models) and the results do not apply to the effect that context may have on other learning outcomes. Also, the conclusions can be expected to apply to contextualised laboratories that include real equipment, rather than to simulation laboratories where the effect of not having real equipment changes students' perceptions and may affect the learning outcome concerning models. The scope also limited the research to measuring the effect of the domain context, and the research did not consider individual differences such as learning styles or student demographics in 'matching' the treatment and control groups.

The technical implementation of the test platform meant that not all contextual elements could be implemented as designed. This led to some of the animated and interactive components of the context being left out of the final laboratory implementation with possible implications for the research results. (This has been discussed in section 7.1.9.) Additionally, the unavoidably novel nature of the test platform may have had an effect on the results (section 7.1.10).

The study design itself imposed limitations (sections 7.1.11 and 7.1.12). Selection of the pretest-posttest control group design as the most suitable research approach, introduced the possible effect of pretesting on student learning outcomes. In the case of this research it may have contributed to masking any effect of the domain context by providing advanced organisers through the prompting questions to all particpants in the study. In addition, the assessment of the scores was done on a test developed specifically for this research. While the test items were taken from existing assessments where possible, the combination was unique and no baseline or verification of the measurements was available.

The practicalities of the study meant that the laboratory work was completed in groups as required for the course time availability. This introduced the factor of group work to the participants' responses. Significantly, the selection of the student cohort meant that all participants had had prior exposure a laboratory investigating the same model which may have provided all participants with context generating information and masked the effects from the laboratory domain context (see section 7.2.1). In addition, testing for the posttest was done within the same laboratory session leaving little time for participants to reflect on their learning (section 7.2.3).

Where possible, measures were taken to reduce the effect of these limitations. However they must be considered in applying the results to other populations, laboratories and learning environments. For example, the results can be more reliably generalised to lab activities done in small groups, where a pretest or prework on the learning outcome is completed by students.

8.4 Future Work

There are a number of questions raised by the outcomes of this research that can be investigated more thoroughly in future work, such as the possible effect that previous exposure to the model has had. In addition, this research study has provided new opportunities for further research to build on, such as the re-usable interface between Open Wonderland and iLabs.

Most notable are those avenues for future work that could support the research findings here:

- *Kokinovs's idea of context: Does contextualisation of a laboratory activity have an effect on learning outcomes when there is no prior exposure to the model?*
  Having argued that the cohorts' prior exposure to the inverse square model may have meant that the possible effects of the domain context were not significant enough to make a difference to the treatment group participants, it would be of interest to investigate whether removing this prior knowledge would have an effect. Any investigation which measures and controls for participants' prior exposure to the model under study would require a carefully considered selection of the model and student cohort, possibly selecting high school students being introduced to a concept for the first time.
- *Interaction vs Awareness: Is interaction with context more effective in improving learning outcomes in laboratories than the static awareness of context?*
  In order to investigate the possible difference in outcomes between 'interactivity' and 'awareness' of context, a measure of the level of interactivity/awareness must be established. In addition, the laboratory testing environment should allow participants the possibility to interact with contextual elements (this is done in other research using game-based labs, or the inclusion of non-player characters within a virtual world). There is research that measures where participants look on a computer screen and logs their interactions within a virtual world. Such measures would be useful in determining whether participants choose to interact with contextual elements and whether there is any correlation between the level of interaction/awareness and learning outcomes. In the case that new context is designed, indications from this research that participants prefer a more realistic virtual world should be considered.
- *Timing: Does contextualisation of a laboratory provide improvements in learning outcomes if time is allowed for reflection?*
  This research allowed participants little time for reflection on the learning activity and did not measure recall due to the timing of the posttest. While it would be challenging to design a study that would allow time for reflection and still control the context generating elements that participants are exposed to, such research would indicate whether the elapsed time allowed for the effect of the domain context presented to the treatment group to be statistically significant.

The limitations of this research too provide indications for where this research can be built on in future work:

- *Are there correlations between context, individual differences and learning outcomes?* Information on aspects that affect learning such as student demographics, learning preferences and abilities did not form part of this research project. It is suggested that future work in the area could mine the data collected here and investigate aspects such as group composition, gender, participants' learning styles or participants' abilities to determine whether these factors have a correlation with learning outcomes.
- *Does using standard test items such as a concept inventory improve the measurement of learning outcomes?* The measurements of learning outcomes was done using an assessment unique to this research. The literature describes a number of robust assessments including concept inventories (large banks of questions testing a specific concept such as Newton's Laws of motion) and using one of these inventories may increase the reliability of learning outcome measurements for future research into models.

This research has also contributed new knowledge that may be used in future research in the field.

- *Further lab integration* The development of the integrated system has resulted in a re-useable interface between Open Wonderland and iLabs batch laboratories. This can be used for future research into the possibilities that virtual worlds present for laboratory learning outcomes such as allowing collaboration or increased student engagement.
- *Context Framework* The research has resulted in a potentially useful framework for the analysis of context in laboratories. Future work may include application of this framework to the analysis of existing laboratories to determine the level of contextualisation and how the functions of contextualisation are fulfilled in each case.

8.5 Chapter Summary

This chapter has covered the following:

- A complete summary of the research presented in this thesis.
- A discussion of the contributions that this research has made to knowledge, specifically new knowledge in how context can affect laboratory learning activities, a newly defined

context framework, a re-useable interface for Open Wonderland and iLabs laboratories and language clarifying the relationship between context, models, laboratories and the real world.

- Limitations to the research which affect how the results should be interpreted and applied have been presented in terms of the scope of the research, the limitations imposed from the study design and the practical considerations of conducting the research.
- Possible future work that can be identified from this research has been described.

References

Abdulwahed, M., Nagy, Z., & Blanchard, R. (2008). Beyond the classroom walls: Remote labs, authentic experimentation with theory lectures. In L. Mann, A. Thompson, & P. Howard (Eds.), *19th Annual Conference of the Australasian Association for Engineering Education: To Industry and Beyond; Proceedings of the* (435–440). Retrieved from https://dspace.lboro.ac.uk/2134/4938.

Adams, W. K., Reid, S. A. M., Lemaster, R. O. N., Mckagan, S. B., Perkins, K. K., Dubson, M., & Wieman, C. E. (2008). A study of educational simulations Part II - Interface design. *Journal of Interactive Learning Research*, 19 (4), 551–577. Retrieved from http://www.editlib.org/j/JILR/.

Akpan, J. P. (2001). Issues associated with inserting computer simulations into biology instruction: A review of the literature. *Electronic Journal of Science Education*, 5 (3). Retrieved from http://ejse.southwestern.edu/.

Ausubel, D. P. (1960). The use of advance organizers in the learning and retention of meaningful verbal material. *Journal of Educational Psychology*, 51 (5), 267–272. DOI: 10.1037/h0046669.

Ausubel, D. P. (1978). In defense of advance organizers: A reply to the critics. *Review of Educational Research*, 48 (2), 251–257. Retrieved from http://www.jstor.org/stable/1170083.

Ausubel, D. P. & Fitzgerald, D. (1961). The role of discriminibility in meaningful verbal learning and retention. *Journal of Educational Psychology*, 52 (5), 266–274.

Azuma, R. T. (1997). A survey of augmented reality. *Presence*, 6 (4), 355–385. Retrieved from http://www.mitpressjournals.org/loi/pres.

Back, M., Kimber, D., Rieffel, E., & Dunnigan, A. (2010). The virtual chocolate factory: Building a real world mixed-reality system for industrial collaboration and control. In *Multimedia and Expo (ICME), 2010 IEEE International Conference on* (pp. 1160–1165). EEE. DOI: 10.1109/ICME.2010.5582532.

Bailer-Jones, D. (2002). Models, metaphors and analogies. In P. Machamer & M. Silberstein (Eds.), *The Blackwell Guide to the Philosophy of Science* (pp. 108–127). Blackwell Publishers.

Bailer-Jones, D. (2003). When scientific models represent. *International Studies in the Philosophy of Science*, 17 (1), 59–74. DOI: 10.1080/02698590305238.

Balsam, P. & Tomie, A. (2014). *Context and Learning*. Psychology Press.

Barab, S. & Dede, C. (2007). Games and immersive participatory simulations for science education: An emerging type of curricula. *Journal of Science Education and Technology*, 16 (1), 1–3. DOI: 10.1007/s10956-007-9043-9.

Barab, S., Dodge, T., & Tuzun, H. (2007). The Quest Atlantis project: A socially-responsive play space for learning. In B. E. Shelton & D. Wiley (Eds.), *The Educational Design and Use of Simulation Computer Games in Education* (pp. 159–186). Rotterdam, The Netherlands: Sense Publishers. Retrieved from http://www.researchgate.net/publication/242406487.

Barab, S., Zuiker, S., Warren, S., Hickey, D, Ingram-Goble, A., Kwon, E.-J., ... Herring, S. C. (2007). Situationally embodied curriculum: Relating formalisms and contexts. *Science Education*, 91 (5), 750–782. DOI: 10.1002/sce.20217.

Bay, L. (1995). *Detection of cheating on multiple-choice examinations*. Paper presented at the annual meeting of the American Educational Research Association. San Francisco, CA. Retrieved from http://eric.ed.gov/?id=ED421530.

Bender, E. A. (1978). *An introduction to mathematical modeling*. Courier Corporation.

Bennett, J., Lubben, F., & Hogarth, S. (2007). Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Science Education*, 93 (1), 347–370. DOI: 10.1002/sce.20186.

Borrego, M., Douglas, E. P., & Amelink, C. T. (2009). Quantitative, qualitative, and mixed research methods in engineering education. *Journal of Engineering Education*, 98 (1), 53–66. DOI: 10.1002/j.2168-9830.2009.tb01005.x.

Boulos, M. N. K., Hetherington, L., & Wheeler, S. (2007). Second Life: An overview of the potential of 3-D virtual worlds in medical and health education. *Health Information & Libraries Journal*, 24 (4), 233–245. DOI: 10.1111/j.1471-1842.2007.00733.x.

Boulter, C. J. & Buckley, B. C. (2000). Constructing a typology of models for science education. In J. K. Gilbert & C. J. Boulter (Eds.), *Developing Models in Science Education* (pp. 41–57). Springer Netherlands. DOI: 10.1007/978-94-010-0876-1_3.

Box, G. E. P. (1976). Science and statistics. *Journal of the American Statistical Association*, 71 (356), 791–799. DOI: 10.1080/01621459.1976.10480949.

Bright, C., Lindsay, E., Lowe, D. B., Murray, S., & Liu, D. (2008). Factors that impact learning outcomes in remote laboratories. In J. Luca & E. Weippl (Eds.), *Proceedings of EdMedia:*

World Conference on Educational Media and Technology 2008 (pp. 6251–6258). Retrieved from http://www.aace.org/conf/edmedia/.

Brown, J. S., Collins, A., Duguid, P., & Seely, J. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18 (1), 32–42. DOI: 10.3102/0013189X018001032.

Burton, R. F. (2005). Multiple-choice and true/false tests: Myths and misapprehensions. *Assessment & Evaluation in Higher Education*, 30 (1), 65–72. DOI: 10.1080/0260293042003243904.

Callaghan, M. J., McCusker, K., Lopez Losada, J., Harkin, J. G., & Wilson, S. (2012). Circuit Warz, the games: Collaborative and competitive game-based learning in virtual worlds. In *Remote Engineering and Virtual Instrumentation (REV), 2012 9th International Conference on* (pp. 1–4). DOI: 10.1109/REV.2012.6293095.

Callaghan, M. J., McCusker, K., Losada, J. L., Harkin, J., & Wilson, S. (2013). Using game-based learning in virtual worlds to teach electronic and electrical engineering. *Industrial Informatics, IEEE Transactions on*, 9 (1), 575–584. DOI: 10.1109/TII.2012.2221133.

Campbell, D. T., Stanley, J. C., & Gage, N. L. (1963). *Experimental and quasi-experimental designs for research*. Boston: Houghton Mifflin.

Campbell, J. O., Bourne, J. R., Mosterman, P. J., & Brodersen, A. J. (2002). The effectiveness of learning simulations for electronic laboratories. *Journal of Engineering Education*, 91 (1), 81–87. DOI: 10.1002/j.2168-9830.2002.tb00675.x.

Cassola, F., Morgado, L., de Carvalho, F., Paredes, H., & Fonseca, B. (2014). Online-Gym: A 3D virtual gymnasium using Kinect interaction. *Procedia Technology*, 13, 130–138. DOI: 10.1016/j.protcy.2014.02.017.

Chambel, T., Zahn, C., & Finke, M. (2004). Hypervideo design and support for contextualized learning. In *Advanced Learning Technologies, 2004. Proceedings. IEEE International Conference on* (pp. 345–349). DOI: 10.1109/ICALT.2004.1357433.

Chang, V., Gütl, C., Kopeinik, S., & Williams, R. (2009). Evaluation of collaborative learning settings in 3D virtual worlds. *International Journal of Emerging Technologies in Learning (iJET)*, 4 (2009), 6–17. Retrieved from http://www.i-jet.org.

Chapman, D. D. & Stone, S. J. (2010). Measurement of outcomes in virtual environments. *Advances in Developing Human Resources*, 12 (6), 665–680. DOI: 10.1177/1523422310394792.

Chen, S. (2010). The view of scientific inquiry conveyed by simulation-based virtual laboratories. *Computers & Education*, 55 (3), 1123–1130. DOI: 10.1016/j.compedu.2010.05.009.

Clark, D., Nelson, B., Sengupta, P., & Angelo, C. D. (2009). Rethinking science learning through digital games and simulations: Genres, examples, and evidence. In *Learning science: Computer games, simulations, and education*. Washington, D.C. Retrieved from http://nationalacademies.org/.

Clark, R. E. & Sugrue, B. M. (1998). Research on instructional media, 1978-1988. In D. Ely (Ed.), *Educational Media and Technology Yearbook*. Littletown, CO: Libraries Unlimited.

Coffman, T. & Klinger, M. (2007). Utilizing virtual worlds in education: The implications for practice. *International Journal of Social Sciences*, 2 (1), 29–33. Retrieved from http://www.iises.net/international-journal-of-social-sciences.html.

Coito, F. & Palma, L. B. (2008). A remote laboratory environment for blended learning. In *Proceedings of the 1st International Conference on Pervasive Technologies Related to Assistive Environments* (69:1–69:4). Australasian Association for Engineering Education. DOI: 10.1145/1389586.1389667.

Coll, R., France, B., & Taylor, I. (2005). The role of models and analogies in science education: Implications from research. *International Journal of Science Education*, 27 (2), 183–198. DOI: 10.1080/0950069042000276712.

Cook, D. L. (1962). The Hawthorne effect in educational research. *Phi Delta Kappan*, 44 (3), 116–122. Retrieved from http://www.jstor.org/stable/20342865.

Cooper, M. & Ferreira, J. M. M. (2009). Remote laboratories extending access to science and engineering curricular. *IEEE Transactions on Learning Technologies*, 2 (4), 342–353. DOI: 10.1109/TLT.2009.43.

Corter, J. E., Esche, S. K., Chassapis, C., Ma, J., & Nickerson, J. V. (2011). Process and learning outcomes from remotely-operated, simulated, and hands-on student laboratories. *Computers & Education Education*, 57 (3), 2054–2067. DOI: 10.1016/j.compedu.2011.04.009.

Corter, J. E., Nickerson, J. V., Esche, S. K., Chassapis, C., Im, S., & Ma, J. (2007). Constructing reality: A study of remote, hands-on, and simulated laboratories. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 14 (2). DOI: 10.1145/1275511.1275513.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Crouch, R. & Haines, C. (2004). Mathematical modelling: transitions between the real world and the mathematical model. *International Journal of Mathematical Education in Science and Technology*, 35 (2), 197–206. DOI: 10.1080/00207390310001638322.

Dalgarno, B. (2002). The potential of 3D virtual learning environments: A constructivist analysis. *Electronic Journal of Instructional Science and Technology*, 5 (2). Retrieved from http://ascilite.org/archived-journals/e-jist/.

Dalgarno, B. (2012). *The potential of virtual laboratories for distance education science teaching: Reflections from the development and evaluation of a virtual chemistry laboratory*. Poster presentation in Proceedings of The Australian Conference on Science and Mathematics Education (formerly UniServe Science Conference). Retrieved from http://openjournals.library.usyd.edu.au/index.php/IISME/.

Dalgarno, B. & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, 41 (1), 10–32. DOI: 10.1111/j.1467-8535.2009.01038.x.

Davenz, Kpr777, Micheldenis, Matty_x, & Technobuddhist. (2008). Wonderland "vs" SecondLife "vs" OpenSim [Discussion list messages]. Retrieved from https://www.java.net/node/685540.

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching test*, 37 (6), 582–601. DOI: 10.1002/1098-2736(200008)37:6⟨582::AID-TEA5⟩3.0.CO;2-L.

Delacoux, C. & Perrin, N. (2009). *Link between hardware and Second Life: Washing machine simulator*. Retrieved from http://isrc.ulster.ac.uk/.

Demetriadis, S. N., Papadopoulos, P. M., Stamelos, I. G., & Fischer, F. (2008). The effect of scaffolding students' context-generating cognitive activity in technology-enhanced case-based learning. *Computers & Education*, 51 (2), 939–954. DOI: 10.1016/j.compedu.2007.09.012.

Dickey, M. D. (2003). Teaching in 3D: Pedagogical affordances and constraints of 3D virtual worlds for synchronous distance learning. *Distance Education*, 24 (1), 105–121. DOI: 10.1080/01587910303047.

Dickey, M. D. (2005). Three-dimensional virtual worlds and distance learning: Two case studies of Active Worlds as a medium for distance education. *British Journal of Educational Technology*, 36 (3), 439–451. DOI: 10.1111/j.1467-8535.2005.00477.x.

Duit, R. (1991). On the role of analogies and metaphors in learning science. *Science Education*, 75 (6), 649–672. DOI: 10.1002/sce.3730750606.

Duit, R. & Treagust, D. F. (1998). Learning in science - from behaviourism towards social constructivism and beyond. In B. J. Fraser & K. G. Tobin (Eds.), *International Handbook of Science Education* (pp. 3–26). Boston: Kluwer.

Duit, R. & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education*, 25 (6), 671–688. DOI: 10.1080/09500690305016.

Edgar, D. W. (2012). Learning theories and historical events affecting instructional design in education: Recitation literacy toward extraction literacy practices. *SAGE Open*, 2 (4). DOI: 10.1177/2158244012462707.

Ellis, T. J. & Levy, Y. (2010). A guide for novice researchers: Design and development research methods. In *Proceedings of Informing Science & IT Education Conference (InSITE)* (pp. 107–118). Retrieved from http://proceedings.informingscience.org/.

Ertmer, P. & Newby, T. (1993). Behaviorism, cognitivism, constructivism: Comparing critical features from an instructional design perspective. *Performance Improvement Quarterly*, 6 (4), 50–72. DOI: 10.1111/j.1937-8327.1993.tb00605.x.

Fayolle, J., Gravier, C., Yankelovich, N., & Kim, E. (2011). Remote lab in a virtual world for remote control of industrial processes. In *Multimedia and Expo (ICME), 2011 IEEE International Conference on* (pp. 1–4). DOI: 10.1109/ICME.2011.6012049.

Feisel, L. & Rosa, A. (2005). The role of the laboratory in undergraduate engineering education. *Journal of Engineering Education*, 94 (1), 121–130. DOI: 10.1002/j.2168-9830.2005.tb00833.x.

Feisel, L., Peterson, G., Arnas, O., Carter, L., Rosa, A., & Worek, W. (2002). A colloquy on learning objectives for engineering education laboratories. In *Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition* (pp. 16–19). American Society for Engineering Education.

Finkelstein, N. (2005). Learning physics in context: A study of student learning about electricity and magnetism. *International Journal of Science Education*, 27 (10), 1187–1209. DOI: 10.1080/09500690500069491.

Fischer, J., Mitchell, R., & Del Alamo, J. (2007). Inquiry-learning with WebLab: Undergraduate attitudes and experiences. *Journal of Science Education and Technology*, 16 (4), 337–348. DOI: 10.1007/s10956-007-9054-6.

Flores, J. (2011). Connecting Open Wonderland to external services [Web log post]. *The simple Virtual life*. Retrieved from http://josmasflores.blogspot.com.au/2011/02/connecting-open-wonderland-to-external.html.

Frigg, R. & Hartmann, S. (2013). Models in Science. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy. Winter 2013 Edition.* Retrieved from http://plato.stanford.edu/archives/win2013/entries/models-science/.

Frigg, R. & Reiss, J. (2009). The philosophy of simulation: Hot new issues or same old stew? *Synthese*, 169 (3), 593–613. DOI: 10.1007/s11229-008-9438-z.

Garcia-Zubia, J., Irurzun, J., Angulo, I., Hernandez, U., Castro, M., Sancristobal, E., ... San-Cristobal, E. (2010). SecondLab: A remote laboratory under Second Life. In *Education Engineering (EDUCON), 2010 IEEE* (pp. 351–356). DOI: 10.1109/EDUCON.2010.5492556.

Gardner, M., Scott, J., & Horan, B. (2008). Reflections on the use of Project Wonderland as a mixed-reality environment for teaching and learning. In *ReLive08: Researching Learning in Virtual Environments International Conference* (pp. 130–141). Open University Press, Milton Keynes. Retrieved from http://www2.open.ac.uk/relive08/.

Giere, R. N. (2004). How models are used to represent reality. *Philosophy of Science*, 71 (5), 742–752. DOI: 10.1086/425063.

Gilbert, J. K. (2004). Models and modelling: Routes to more authentic science education. *International Journal of Science and Mathematics Education*, 2 (2), 115–130. DOI: 10.1007/s10763-004-3186-4.

Gilbert, J. K. (2006). On the nature of "context" in chemical education. *International Journal of Science Education*, 28 (9), 957–976. DOI: 10.1080/09500690600702470.

Gilbert, J. K. (2008). Visualization: An emergent field of practice and enquiry in science education. In J. K. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and Practice in Science Education* (pp. 3–24). Springer Netherlands. DOI: 10.1007/978-1-4020-5267-5_1.

Gilbert, J. K., Boulter, C. J., & Elmer, R. (2000). Positioning models in science education and in design and technology education. In J. K. Gilbert & C. J. Boulter (Eds.), *Developing Models in Science Education* (pp. 3–18). Springer Netherlands. DOI: 10.1007/978-94-010-0876-1_1.

Gilbert, J. K., Pietrocola, M., Zylbersztjan, A., & Franco, C. (2000). Science and education: Notions of reality, theory and model. In J. K. Gilbert & C. J. Boulter (Eds.), *Developing Models in Science Education* (Vol. 30, pp. 19–41). Springer Netherlands. DOI: 10.1007/978-94-010-0876-1_2.

Gilbert, S. (1989). An evaluation of the use of analogy, simile, and metaphor in science texts. *Journal of Research in Science Teaching*, 26 (4), 315–327. DOI: 10.1002/tea.3660260405.

Girvan, C. & Savage, T. (2010). Identifying an appropriate pedagogy for virtual worlds: A Communal Constructivism case study. *Computers & Education*, 55 (1), 342–349. DOI: 10.1016/j.compedu.2010.01.020.

Godden, D. R. & Baddeley, A. D. (1975). Context-dependent memory in two natural environments: On land and underwater. *British Journal of Psychology*, 66 (3), 325–331. DOI: 10.1111/j.2044-8295.1975.tb01468.x.

Goel, L., Johnson, N., Junglas, I., & Ives, B. (2010). Situated learning: Conceptualization and measurement. *Decision Sciences Journal of Innovative Education*, 8 (1), 215–240. DOI: 10.1111/j.1540-4609.2009.00252.x.

Gravier, C., Fayolle, J., Bayard, B, Ates, M, & Lardon, J. (2008). State of the art about remote laboratories paradigms - foundations of ongoing mutations. *International Journal of Online Engineering (iJOE)*, 4 (1), 19–25. Retrieved from http://www.i-joe.org/.

Grosslight, L, Unger, C., Jay, E., & Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching*, 28 (9), 799–822. DOI: 10.1002/tea.3660280907.

Gustavsson, I., Zackrisson, J, Hå kansson, L, Claesson, I, & Lagö, T. (2007). The VISIR project - an open source software initiative for distributed online laboratories. *Proceedings of the*

Remote Engineering And Virtual Instrumentation Conference. Retrieved from http://www.rev-conference.org/.

Gustavsson, I., Nilsson, K., Zackrisson, J., Garcia-Zubia, J., Hernandez-Jayo, U., Nafalski, A., . . . Hå kansson, L. (2009). On objectives of instructional laboratories, individual assessment, and use of collaborative remote laboratories. *IEEE Transactions on Learning Technologies*, 2 (4), 263–274. DOI: 10.1109/TLT.2009.42.

Hahn, H. & Spong, M. (2000). Remote laboratories for control education. In *Decision and Control, 2000. Proceedings of the 39th IEEE Conference on* (Vol. 1, pp. 895–900). IEEE. DOI: 10.1109/CDC.2000.912884.

Hardison, J. L., Delong, K., Bailey, P. H., & Harward, J. V. (2008). Deploying interactive remote labs using the iLab Shared Architecture. In *Frontiers in Education Conference, 2008. FIE 2008. 38th Annual* (pp. S2A–1 –S2A–6). IEEE. DOI: 10.1109/FIE.2008.4720536.

Harpp, D. N. & Hogan, J. J. (1993). Crime in the classroom: Detection and prevention of cheating on multiple-choice exams. *Journal of Chemical Education*, 70 (4), 306. DOI: 10.1021/ed070p306.

Harward, J. V., del Alamo, J. A., Lerman, S. R., Bailey, P. H., Carpenter, J, DeLong, K, . . . Jabbour, I. (2008). The iLab Shared Architecture: A web services infrastructure to build communities of internet accessible laboratories. *Proceedings of the IEEE*, 96 (6), 931–950. DOI: 10.1109/JPROC.2008.921607.

Hashemi, J., Chandrashekar, N., & Anderson, E. E. (2006). Design and development of an interactive web-based environment for measurement of hardness in metals: A distance learning tool. *International Journal of Engineering Education*, 22 (5), 993–1002. Retrieved from http://www.ijee.ie/.

Hendeby, G., Gustafsson, F., & Wahlström, N. (2014). Teaching sensor fusion and Kalman filtering using a smartphone. In *19th World Congress of the International Federation of Automatic Control (IFAC), IFAC Papers Online, 2014*. DOI: 10.3182/20140824-6-ZA-1003.00967.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher*, 30 (3), 141–158. DOI: 10.1119/1.2343497.

Hofstein, A. & Lunetta, V. N. (1982). The role of the laboratory in science teaching: Neglected aspects of research. *Review of Educational Research*, 52 (2), 201–217. DOI: 10.3102/00346543052002201.

Hofstein, A. & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education*, 88 (1), 28–54. DOI: 10.1002/sce.10106.

Hofstein, A. & Mamlok-Naaman, R. (2007). The laboratory in science education: The state of the art. *Chemistry Education Research and Practice*, 8 (2), 105. DOI: 10.1039/b7rp90003a.

Holton, D. L. (2010). How people learn with computer simulations. In H. Song & T. Kidd (Eds.), *Handbook of Research on Human Performance and Instructional Technology* (pp. 485–504). IGI Global. DOI: 10.4018/978-1-60566-782-9.

Houston, J. P. (1976). The assessment and prevention of answer copying on undergraduate multiple-choice examinations. *Research in Higher Education*, 5 (4), 301–311. DOI: 10.1007/BF00993429.

Huff, T. E. (2003). *The rise of early modern science: Islam, China and the West*. Cambridge University Press.

iCampus, M. *About iLabs*. Retrieved July 24, 2015, from http://icampus.mit.edu/projects/ilabs/.

Jenkins, E. (2007). What is the school science laboratory for? *Journal of Curriculum Studies*, 39 (6), 723–736. DOI: 10.1080/00220270601134425.

Jona, K. & Adsit, J. (2008). Goals, guidelines, and standards for student scientific investigations. *North American Council for Online Learning*. Retrieved from http://www.inacol.org/.

Jona, K., Roque, R., Skolnik, J., Uttal, D., & Rapp, D. (2011). Are remote labs worth the cost? Insights from a study of student perceptions of remote labs. *International Journal of Online Engineering (iJOE)*, 7 (2), 48–53. DOI: 10.3991/ijoe.v7i2.1394.

Jona, K. & Vondracek, M. (2013). A remote radioactivity experiment. *The Physics Teacher*, 51 (25), 25–27. DOI: 10.1119/1.4772033.

Kaplan, J. & Yankelovich, N. (2011). Open Wonderland: An extensible virtual world architecture. *IEEE Internet Computing*, 15 (5), 38–45. DOI: 10.1109/MIC.2011.76.

Kimberly K DeLong. *iLabs Around the World*. Retrieved July 24, 2015, from https://wikis.mit.edu/confluence/display/ILAB2/iLabs.

Klassen, S. (2006). A theoretical framework for contextual science teaching. *Interchange*, 37 (1), 31–62. DOI: 10.1007/s10780-006-8399-8.

Kokinov, B. (1999). Dynamics and Automaticity of Context: A Cognitive Modeling Approach. In P. Bouquet, M. Benerecetti, L. Serafini, P. Brezillon, & F. Castellani (Eds.), *Modeling and Using Context* (Vol. 1688, pp. 200–213). Springer Berlin Heidelberg. DOI: 10.1007/3-540-48315-2_16.

Lee, T. H. C. (2000). *Education in traditional China: A history* (Vol. 13). Leiden: Brill.

Lee, Y.-F., Guo, Y., & Ho, H.-j. (2008). Explore Effective Use of Computer Simulations for Physics Education. *Journal of Computers in Mathematics and Science Teaching*, 27 (4), 443–466. Retrieved from http://www.editlib.org/j/JCMST/.

Leleve, A., Arnous, S., & Prevot, P. (2009). Supporting learning scenario authoring for Electronic Laboratories. In *International Conference on Management of Emergent Digital EcoSystems* (pp. 83:498 –83:505). DOI: 10.1145/1643823.1643925.

Leleve, A., Benmohamed, H., Prevot, P., & Meyer, C. (2003). Remote Laboratory - towards an integrated training system. In *4th International Conference on Information Technology Based Higher Education and Training (ITHET 2003)* (pp. 110–115). Retrieved from http://www.ithet.boun.edu.tr/.

Leung, A. & Merrylands High School: Science Department. (2013). *Hydro lesson*. Retrieved Mar. 04, 2015, from http://www.labshare.edu.au/media/lesson_guides/hydro_school_student_activities_v1.0.pdf.

Levitt, S. & List, J. (2007). What do laboratory experiments measuring social preferences reveal about the real world? *The Journal of Economic Perspectives*, 21 (2), 153–174. Retrieved from http://www.jstor.org/stable/30033722.

Linden Research. (2015). *Second Life*. Retrieved July 27, 2015, from https://community.secondlife.com/t5/tkb/communitypage.

Lindsay, E. & Good, M. (2005). Effects of laboratory access modes upon learning outcomes. *Education, IEEE Transactions on*, 48 (4), 619–631. DOI: 10.1109/TE.2005.852591.

Lindsay, E., Murray, S., Liu, D. K., Lowe, D. B., & Bright, C. (2009). Establishment reality vs. maintenance reality: How real is real enough? *European Journal of Engineering Education*, 34 (3), 229–234. DOI: 10.1080/03043790902902906.

Lindsay, E., Naidu, S., & Good, M. (2007). A different kind of difference: Theoretical implications of using technology to overcome separation in remote laboratories. *International Journal of Engineering Education*, 23 (4), 772–779. Retrieved from http://www.ijee.ie/.

Liu, X. (2006). Effects of combined hands-on laboratory and computer modeling on student learning of gas laws: A quasi-experimental study. *Journal of Science Education and Technology*, 15 (1), 89–100. DOI: 10.1007/s10956-006-0359-7.

Lowe, D. B., Murray, S., Lindsay, E., Liu, D., & Bright, C. (2008). Reflecting professional reality in remote laboratory experiences. *International Conference on Remote Engineering and Virtual Instrumentation (REV 2008)*, 1–5. Retrieved from http://www.rev-conference.org/.

Lowe, D. B., Murray, S., Weber, L, De La Villefromoy, M, Johnston, A, Lindsay, E., … Nafalski, A. (2009). LabShare: Towards a national approach to laboratory sharing. *20th Annual Conference for the Australasian Association for Engineering Education*, 458–463. Retrieved from https://www.engineersaustralia.org.au/australasian-association-engineering-education.

Lowe, R. (2004). Interrogation of a dynamic visualization during learning. *Learning and Instruction*, 14 (3), 257–274. DOI: 10.1016/j.learninstruc.2004.06.003.

Ma, J. & Nickerson, J. V. (2006). Hands-on, simulated, and remote laboratories. *ACM Computing Surveys*, 38 (3), 7–24. DOI: 10.1145/1132960.1132961.

Machet, T. & Lowe, D. B. (2012). Integrating real equipment into virtual worlds. In L. Mann & S. Daniel (Eds.), *Profession of Engineering Education: Advancing Teaching, Research and Careers: 23rd Annual Conference of the Australasian Association for Engineering Education 2012, The* (pp. 195–205). Engineers Australia. Retrieved from https://www.engineersaustralia.org.au/australasian-association-engineering-education.

Machet, T. & Lowe, D. B. (2013). Issues integrating remote laboratories into virtual worlds. In H. Carter, M. Gosper, & J. Hedberg (Eds.), *Proceedings of the 30th ascilite Conference* (pp. 521–525). Retrieved from http://ascilite.org/.

Machet, T. & Lowe, D. B. (in press). An analysis of the provision of context within existing remote laboratories. *Frontiers in Education 2015*.

Machet, T., Lowe, D. B., & Gütl, C. (2012). On the potential for using immersive virtual environments to support laboratory experiment contextualisation. *European Journal of Engineering Education*, 37 (6), 527–540. DOI: 10.1080/03043797.2012.721743.

Machotka, J. & Nedic, Z. (2008). From the collaborative environment of the remote laboratory NetLab to the global collaboration. *International Journal of Online Engineering (iJOE)*, 4 (SI: REV2008), 45–49. Retrieved from http://www.i-joe.org/.

Mäki, U. (2005). Models are experiments, experiments are models. *Journal of Economic Methodology*, 12 (2), 303–315. DOI: 10.1080/13501780500086255.

Marcelino, R., Silva, J. B. D., Alves, G. R., & Shaeffer, L. (2010). Extended immersive learning environment: A hybrid remote/virtual laboratory. *International Journal of Online Engineering (iJOE)*, 6 (SI: REV2010), 46–51. DOI: 10.3991/ijoe.v6s1.1386.

Mason, G., Shih, F., & Dragovich, J. (2007). Real-time access to experimental data using tablet PC's. In *American Society for Engineering Education Annual Conference & Exposition* (pp. 12.1224.1 –12.1224.10). Retrieved from https://peer.asee.org/2179.

Matthews, M. R. (2007). Models in science and in science education: An introduction. *Science & Education*, 16 (7-8), 647–652. DOI: 10.1007/s11191-007-9089-3.

McCoubrie, P. (2004). Improving the fairness of multiple-choice questions: A literature review. *Medical Teacher*, 26 (8), 709–712. DOI: 10.1080/01421590400013495.

McElhaney, K. W. & Linn, M. C. (2008). Impacts of students' experimentation using a dynamic visualization on their understanding of motion. In *Proceedings of the 8th international conference of the learning sciences (ICLS'08)* (Vol. 2, 51–58). International Society of the Learning Sciences. Retrieved from https://www.isls.org/conferences/icls.

Mckagan, S. B., Perkins, K. K., Dubson, M., Malley, C., Reid, S., LeMaster, R., & Wieman, C. E. (2008). Developing and researching PhET simulations for teaching quantum mechanics. *American Journal of Physics*, 76 (4&5), 406–417. DOI: 10.1119/1.2885199.

Merriam-Webster. (2015). *Context*. The Merriam-Webster Online Dictionary. Retrieved from http://www.merriam-webster.com/dictionary/context.

Milgram, P. & Colquhoun Jr., H. (1999). A Taxonomy of Real and Virtual World Display Integration. In Y Ohta & H Tamura (Eds.), *Mixed reality: Merging real and virtual worlds* (pp. 5–30). New York: Springer.

Mujkanovic, A. & Lowe, D. B. (2012). Unsupervised learning algorithm for adaptive group formation: Collaborative learning support in remotely accessible laboratories. In *International Conference on Information Society (i-Society 2012)* (pp. 50–57). IEEE. Retrieved from http://www.i-society.eu/.

Nedic, Z., Machotka, J., & Nafalski, A. (2003). Remote laboratories versus virtual and real laboratories. In *Frontiers in Education, 2003 (FIE 2003). 33rd Annual* (Vol. 1, pp. T3E–1 –T3E–6). DOI: 10.1109/FIE.2003.1263343.

Nickerson, J. V., Corter, J. E., Esche, S, & Chassapis, C. (2007). A model for evaluating the effectiveness of remote engineering laboratories and simulations in education. *Computers & Education*, 49 (3), 708–725. DOI: 10.1016/j.compedu.2005.11.019.

Norman, G. R. & Streiner, D. L. (2003). *PDQ Statistics* (2nd ed.). PMPH-USA.

Norton, C., Cameron, I., Crosthwaite, C., Balliu, N., Tade, M., Shallcross, D., … Kavanagh, J. (2008). Development and deployment of an immersive learning environment for enhancing process systems engineering concepts. *Education for Chemical Engineers*, 3 (2), e75–e83. DOI: 10.1016/j.ece.2008.04.001.

Novak, J. (1976). Understanding the learning process and effectiveness of teaching methods in the classroom, laboratory, and field. *Science Education*, 60 (4), 493–512. DOI: 10.1002/sce.3730600410.

Ogot, M., Elliott, G., & Glumac, N. (2003). An assessment of in-person and remotely operated laboratories. *Journal of Engineering Education*, 92 (1), 57–64. DOI: 10.1002/j.2168-9830.2003.tb00738.x.

Oloruntegbe, K. O. & Alam, G. M. (2010). Evaluation of 3D environments and virtual realities in science teaching and learning: The need to go beyond perception referents. *Scientific Research and Essays*, 5 (9), 948–954. Retrieved from http://www.academicjournals.org/SRE.

Open Wonderland Foundation. (2015). *Open Wonderland*. Retrieved July 27, 2015, from http://openwonderland.org/index.php/about/features.

Overte Foundation. (2015). *OpenSimulator*. Retrieved July 27, 2015, from http://opensimulator.org/wiki/Main_Page.

Overton, T. L. (2001). Teaching chemists to think: From parrots to professionals. *University Chemistry Education*, 5 (2), 62–68. Retrieved from http://www.rsc.org/.

Parsons, D. & Stockdale, R. (2010). Cloud as context: Virtual world learning with Open Wonderland. *Proceedings of the 9th World Conference on Mobile and Contextual Learning (mLearn 2010)*, 123–130. Retrieved from http://www.mlearn.org/mlearn2010/.

Payne, L. & Schulz, M. (2013). JAVA implementation of the batched iLab Shared Architecture. *International Journal of Online Engineering (iJOE)*, 9 (SI: REV2013). DOI: 10.3991/ijoe.v9iS3.2531.

Penner, D. E. (2000). Cognition, computers, and synthetic science: Building knowledge and meaning through modeling. *Review of Research in Education*, 25 (1), 1–35. DOI: 10.3102/0091732X025001001.

Pereira, C. E., Paladini, S., & Schaf, F. M. (2012). Control and automation engineering education: Combining physical, remote and virtual labs. *Systems, Signals and Devices (SSD), 2012 9th International Multi-Conference on*, 1–10. DOI: 10.1109/SSD.2012.6197908.

Piotr F Mitros. *The iLab Shared Architecture*. Retrieved July 24, 2015, from https://wikis.mit.edu/confluence/display/ILAB2/Developers.

Pirker, J., Berger, S., Gütl, C., & Belcher, J. (2012). Understanding physical concepts using an immersive virtual learning environment. In *Proceedings of the 2nd European Immersive Education Summit*. Paris. Retrieved from http://immersiveeducation.org/.

Pringle, D. L. & Henderleiter, J. (1999). Effects of context-based laboratory experiments on attitudes of analytical chemistry students. *Journal of Chemical Education*, 76 (1), 100–106. DOI: 10.1021/ed076p100.

Prins, G., Bulte, A., Van Driel, J., & Pilot, A. (2008). Selection of authentic modelling practices as contexts for chemistry education. *International Journal of Science Education*, 30 (14), 1867–1890. DOI: 10.1080/09500690701581823.

Rashid, M., Tasadduq, I. A., Zia, Y. I., Al-turkistany, M., & Rashid, S. (2012). A methodology for the assessment of pedagogic and implementation aspects of laboratories. In *Proceedings of the International Conference on Frontiers in Education: Computer Science and Computer Engineering (FECS)*.

Richter, T., Tetour, Y., & Boehringer, D. (2011). Library of Labs - A European project on the dissemination of remote experiments and virtual laboratories. In *2011 IEEE International Symposium on Multimedia* (pp. 543–548). IEEE. DOI: 10.1109/ISM.2011.96.

Rudolph, J. L. (2005). Epistemology for the masses: The origins of “the scientific method” in American schools. *History of Education Quarterly*, 45 (3), 341–376. DOI: 10.1111/j.1748-5959.2005.tb00039.x.

Sancristobal, E., Martin, S., Gil, R., Díaz, G., Colmenar, A., Castro, M., … López, P. (2008). Integration of internet based labs and open source LMS. In *Internet and Web Applications* *and Services, 2008. ICIW '08. Third International Conference on* (pp. 217–222). IEEE. DOI: 10.1109/ICIW.2008.45.

Sauter, M., Uttal, D. H., Rapp, D. N., Downing, M., & Jona, K. (2013). Getting real: The authenticity of remote labs and simulations for science learning. *Distance Education*, 34 (1), 37–47. DOI: 10.1080/01587919.2013.770431.

Savage, C, Mcgrath, D, Mcintyre, T, Wegener, M, & Williamson, M. (2010). Teaching physics using virtual reality. *International Conference on Physics Education, ICPE-2009*, 1263 (1), 126–129. DOI: 10.1063/1.3479848.

Scheucher, B. (2010). Remote physics experiments in 3D virtual environment. (Masters Thesis, Graz University of Technology). Retrieved from http://info.iicm.tu-graz.ac.at/thesis/.

Scheucher, B., Bailey, P. H., Gütl, C, & Harward, J. V. (2009). Collaborative virtual 3D environment for internet-accessible physics experiments. *International Journal of Online Engineering (iJOE)*, 5 (SI: REV2009), 65–71. Retrieved from http://www.i-joe.org/.

Scheucher, B., Belcher, J. W., Bailey, P. H., Fabio, R, & Gütl, C. (2009). Evaluation results of a 3D virtual environment for internet- accessible physics experiments. In *International Conference of Interactive Computer Aided Learning*. Retrieved from http://www.icl-conference.org/.

Schmidt, M. (2011). Using the Kinect as an input device for Open Wonderland [Web log post]. *Wonderblog*. Retrieved from http://blogs.openwonderland.org/2011/04/25/using-the-kinect-as-an-input-device-for-open-wonderland/.

Schulz, M., Rudd, A., & Payne, L. (2012). RESTlabs: Service Broker architecture for remote labs. In *9th International Conference on Remote Engineering and Virtual Instrumentation, REV 2012* (pp. 1–6). IEEE. DOI: 10.1109/REV.2012.6293171.

Schunk, D. H. (2012). *Learning theories: An educational perspective* (6th ed.). Boston, MA: Pearson.

Séré, M.-G., Leach, J., Niedderer, H., Psillos, D., & Vicentini, M. (1998). Improving science education: Issues and research on innovative empirical and computer-based approaches to labwork in Europe. In *Final report from Labwork in Science Education*.

Smith, S., Glenberg, A., & Bjork, R. (1978). Environmental context and human memory. *Memory & Cognition*, 6 (4), 342–353. DOI: 10.3758/BF03197465.

Snowden, C., II. (2011). The iLab Project [Figure]. Retrieved July 24, 2015, from https://wikis.mit.edu/confluence/display/ILAB2/Home.

Syamsuddin, M. R., Lee, C. H., & Kwon, Y.-M. (2009). Research on VRI: Virtual world and real world interface. In *International Symposium on Ubiquitous Virtual Reality, 2009* (pp. 72–75). IEEE. DOI: 10.1109/ISUVR.2009.17.

Tessmer, M. & Richey, R. C. (1997). The role of context in learning and instructional design. *Educational Technology Research and Development*, 45 (2), 85–115. DOI: 10.1007/BF02299526.

Thompson, C. W. (2011). Next-generation virtual worlds: Architecture, status, and directions. *Internet Computing*, 15 (1), 60–65. DOI: 10.1109/MIC.2011.15.

Thornton, R. K. (1998). Assessing student learning of Newtons laws: The force and motion conceptual evaluation and the evaluation of active learning laboratory and lecture curricula. *American Journal of Physics*, 66 (4), 338. DOI: 10.1119/1.18863.

Tobin, K. (1990). Research on science laboratory activities: In pursuit of better questions and answers to improve learning. *School Science and Mathematics*, 90 (5), 403–418. DOI: 10.1111/j.1949-8594.1990.tb17229.x.

Trevelyan, J. P. (2004). Lessons learned from 10 years experience with remote laboratories. In *iCEER 2004: International Conference on Engineering Education and Research Progress Through Partnership* (pp. 687–697). Retrieved from http://www.ineer.org/.

Trigwell, K. & Prosser, M. (1991). Improving the quality of student learning: The influence of learning context and student approaches to learning on learning outcomes. *Higher Education*, 22 (3), 251–266. DOI: 10.1007/BF00132290.

Trumper, R. (2003). The physics laboratory - A historical overview and future perspectives. *Science & Education*, 12 (7), 645–670. DOI: 10.1023/A:1025692409001.

University of Sydney. (2014). *Health Physics and Radiation Biology (MRTY1036)*. Retrieved Nov. 02, 2014, from http://sydney.edu.au/courses/uos/MRTY1036/health-physics-and-radiation-biology.

van Oers, B. (1998). From context to contextualising. *Learning and Instruction*, 8 (6), 473–488. DOI: 10.1016/S0959-4752(98)00031-0.

Warburton, S. (2009). Second Life in higher education: Assessing the potential for and the barriers to deploying virtual worlds in learning and teaching. *British Journal of Educational Technology*, 40 (3), 414–426. DOI: 10.1111/j.1467-8535.2009.00952.x.

Wesolowsky, G. O. (2000). Detecting excessive similarity in answers on multiple choice exams. *Journal of Applied Statistics*, 27 (7), 909–921. DOI: 10.1080/02664760050120588.

Winn, W., Windschitl, M., Fruland, R., & Lee, Y. (2002). When does immersion in a virtual environment help students construct understanding? In *Proceedings of the International Conference of the Learning Sciences, ICLS* (pp. 497–503). Retrieved from https://www.isls.org/.

Wofford, J. (2008). K-16 computationally rich science education: A ten-year review of the Journal of Science Education and Technology (1998-2008). *Journal of Science Education and Technology*, 18 (1), 29–36. DOI: 10.1007/s10956-008-9127-1.

Wynne, N. (2010). COMSLIVE - Communication skills learning in immersive virtual environments [Web log post]. *Wonderblog*. Retrieved from http://blogs.openwonderland.org/2010/02/26/comslive-?--communication-skills-learning-in-immersive-virtual-environments/.

Yan, Y., Liang, Y., Du, X., Saliah-hassane, H., & Ghorbani, A. (2006). Putting labs online with Web services. *IT Professional*, 8 (2), 27–34. DOI: 10.1109/MITP.2006.45.

Yang, B. (2003). Towards a holistic theory of knowledge and adult learning. *Human Resource Development Review*, 2 (2), 106–129. DOI: 10.1177/1534484303002002002.

Yankelovich, N. (2009). Marble physics [Web log post]. *Wonderblog*. Retrieved from http://blogs.openwonderland.org/2009/08/12/marble-physics.

Yeung, H., Lowe, D. B., & Murray, S. (2010). Interoperability of remote laboratories systems. *International Journal of Online Engineering (iJOE)*, 6 (SI: REV2010), 71–80. DOI: 10.3991/ijoe.v6s1.1387.

Zutshi, A. & Sharma, G. (2009). A study of virtual environments for enterprise collaboration. In *Proceedings of the 8th International Conference on Virtual Reality Continuum and its Applications in Industry* (pp. 331–333). DOI: 10.1145/1670252.1670327.

Appendix A

ABET Learning Objectives

These objectives are taken directly from Feisel and Rosa, 2005, p. 127.

Through completing labs within an engineering curriculum, students should be able to:

1. Objective 1: Instrumentation.
   Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.
2. Objective 2: Models.
   Identify the strengths and limitations of theoretical models as predictors of real-world behaviors. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.
3. Objective 3: Experiment.
   Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterize an engineering material, component, or system.
4. Objective 4: Data Analysis.
   Demonstrate the ability to collect, analyze, and interpret data, and to form and support conclusions. Make order of magnitude judgments and use measurement unit systems and conversions.
5. Objective 5: Design.
   Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using

appropriate tools to satisfy requirements.

6. Objective 6: Learn from Failure.
   Identify unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then re-engineer effective solutions.
7. Objective 7: Creativity.
   Demonstrate appropriate levels of independent thought, creativity, and capability in real-world problem solving.
8. Objective 8: Psychomotor.
   Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.
9. Objective 9: Safety.
   Identify health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.
10. Objective 10: Communication.
    Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.
11. Objective 11: Teamwork.
    Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.
12. Objective 12: Ethics in the Laboratory.
    Behave with highest ethical standards, including reporting information objectively and interacting with integrity.
13. Objective 13:
    Sensory Awareness. Use the human senses to gather information and to make sound engineering judgments in formulating conclusions about real-world problems.

Appendix B

Hydroelectric Energy Case Study

This chapter includes extracts from the hydroelectric energy laboratory activity plans for high school students including the energy conversion activity used in the case study (Leung & Merrylands High School: Science Department, 2013).

Student Activities

These student activities are designed to be self-paced activities that students can complete independently or in small groups. Alternatively they can also be used as a teacher demonstration. All activity sheets can be downloaded in Microsoft Word formats so that teachers can edit the sheets to meet the needs of their students.

Energy Transformations

UTS remote lab rig: Hydro rig

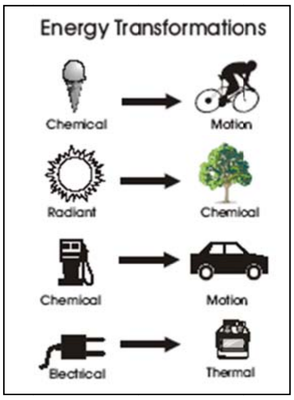
Year level: 7, 8
Syllabus links:
NSW Science Syllabus
4.6.1 the law of conservation of energy
a) identify situations or phenomena in which different forms of energy are evident
b) qualitatively account for the total energy involved in energy transfers and transformations
Australian Curriculum
Year 8 Physical Sciences - Energy appears in different forms including movement (kinetic energy), heat and potential energy and causes changes within systems

Summary of student activity
Students control a water wheel to power four lights in a model house. Students control the amount the water valve is opened in order to control the amount of energy the water wheel generates to light up the house.
Download the energy transformations student activity sheet

Energy transformations

Energy is the ability to do work, which includes the ability to move something or to change the shape of something. Energy comes in different forms such as heat, light, motion, electrical, chemical, nuclear and gravitational. Types of energy can be sorted into two groups: stored (potential) or moving (kinetic).

Energy cannot be created or destroyed. Energy can only change from one type to another. While energy can change form, the total amount of energy in the universe stays the same. When one type of energy changes to another type, it is called an **energy transformation**. Energy transformations can be represented using arrows. Eg. chemical → kinetic means chemical energy has changed into kinetic energy.

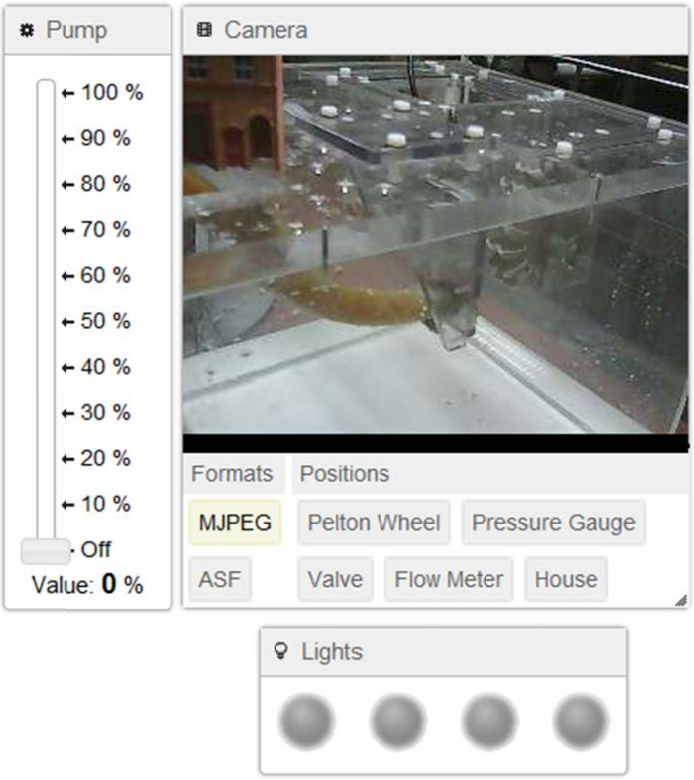


Source: National Energy Education Development Project (Public Domain)

Activity – Water wheel experiment

In this activity you will control a water wheel to see types of energy changing into other types of energy. Your teacher will help you log on to UTS remote labs to access the water wheel, in the Hydro rig.

1. Log on to UTS remote labs and select the Hydro rig.
2. Select the Basics 1 experiment.
3. Leave the valve pump at 0%. This means the pump is not turned on.
4. Explore the equipment by clicking on the Pelton wheel, pressure gauge, valve, flow meter and house.



5. Set the valve of the pump at 10%. This means the valve is opened at 10% its capacity. Observe the number of lights that turn on at the house and record the results in the table below.
6. Increase the valve to 20%. Observe the number of lights that turn on at the house and record the results in the table below.
7. Repeat step 6 but increase the valve percentage each time until your reach 100%.

Results

Pump valve opened at (%)	Number of lights turned on

Discussion questions

1. How do the lights at the house turn on and off?

____

____

____

2. What provides the energy to turn the lights on?

____

____

3. How does the energy that turns on the lights increase and decrease?

____

____

____

____

4. How do you know that energy has increased or decreased?

____

____

5. Use arrows to list as many energy transformations you can find in the Hydro rig.
   Eg. *kinetic energy → electrical energy*

____

____

____

____

6. How does the energy provided by the pump compare with the energy used to turn the wheel and the energy used to turn on the lights?

____

____

____

____

Appendix C

iLabs Specifications

The following messages make up the ServiceBroker API for this development and support batched iLabs experiments within Open Wonderland. Sourced from Harward et al. (2008).

```
GetLabStatus:
 purpose: Checks on the status of the lab server
 arguments: none
 returns: Labstatus

         public struct LabStatus
         {
            public readonly bool online
               /* true if lab is accepting experiments */
            public readonly string labStatusMessage
               /* domain-dependent human-readable text describing status of lab
                   server. */
         }
```

```
GetEffectiveQueueLength:
  purpose: Checks on the effective queue length of the lab server.
      The notion of an 'effective queue' is the answer to the following
          question: hypothetically, if a user belonging to the specified
          userGroup were to submit a new experiment right now with the
          specified priorityHint, how many of the experiments currently in the
          execution queue would run before the new experiment?
   arguments:
      string userGroup
```

```
        /* effective group of the user submitting the hypothetical new
            experiment */
     int priorityHint
        /* indicates a requested priority for the hypothetical new experiment.
            Possible values range from 20 (highest priority) to -20 (lowest
            priority); 0 is normal.   Priority hints may or may not be
            considered by the lab server */
   returns: WaitEstimate

        public struct WaitEstimate
        {
           public readonly int effectiveQueueLength
                /* number of experiments currently in the execution queue that
                    would run before the hypothetical new experiment */
           public readonly double estWait
                /* [OPTIONAL, < 0 if not supported] estimated wait (in
                    seconds) until the hypothetical new experiment would
                    begin, based on the other experiments currently in the
                    execution queue */
        }
```

```
GetLabInfo:
   purpose: Gets general information about a lab server.
   arguments: none
   returns: string URL
        /* a URL to a lab-specific information resource, e.g. a lab
            information page. */
```

```
GetLabConfiguration:
   purpose: Gets the lab configuration of a lab server.
   arguments:
     string userGroup
        /* effective group of the user requesting the lab configuration. */
   returns:
     string labConfiguration
        /* an opaque, domain-dependent lab configuration. */
```

```
Validate:
```

```
  purpose: Checks whether an experiment specification would be accepted if
      submitted for execution.
  arguments:
    string experimentSpecification
      /* an opaque, domain-dependent experiment specification. */
    string userGroup
    /* effective group of the user submitting this experiment. */
  returns: ValidationReport

      public struct ValidationReport
      {
        public readonly bool accepted
          /* true iff the experiment specification would be (is) accepted
              for execution. */
        public readonly string[] validationWarningMessages
          /* domain-dependent human-readable text containing non-fatal
              warnings about the experiment. */
        public readonly string validationErrorMessage
          /* [if accepted == false] domain-dependent human-readable text
              describing why the experiment specification would not be (is
              not) accepted. */
        public readonly double estRuntime
          /* [OPTIONAL, < 0 if not supported] estimated runtime (in
              seconds) of this experiment. */
}
```

```
Submit:
  purpose: Submits an experiment specification to the lab server for
      execution.
  arguments:
    int experimentID
      /* the identifying token that can be used to inquire about the status
          of this experiment and to retrieve the results when ready. */
    string experimentSpecification
      /* an opaque, domain-dependent experiment specification. */
    string userGroup
      /* effective group of the user submitting this experiment. */
    int priorityHint
```

```
      /* indicates a requested priority for this experiment. Possible values
         range from 20 (highest priority) to - 20 (lowest priority); 0 is
         normal. Priority hints may or may not be considered by the lab
         server. */
  returns: SubmissionReport

      public struct SubmissionReport
      {
        public readonly ValidationReport vReport;
          /* see Validate() */
        public readonly double minTimeToLive
          /* guaranteed minimum time (in hours, starting now) before this
             experimentID and associated data will be purged from the lab
             server */
        public readonly WaitEstimate wait;
          /* see GetEffectiveQueueLength() */
      }
```

```
Cancel:
  purpose: Cancels a previously submitted experiment. If the experiment is
     already running, makes best efforts to abort execution, but there is no
     guarantee that the experiment will not run to completion.
  arguments:
    int experimentID
      // a token that identifies the experiment
  returns:
    bool cancelled
      /* true iff experiment was successfully removed from the queue (before
         execution had begun). If false, user may want to call
         GetExperimentStatus() for more detailed information. */
```

```
GetExperimentStatus:
  purpose: Checks on the status of a previously submitted experiment.
  arguments:
    int experimentID
      // a token that identifies the experiment
  returns: LabExperimentStatus

    public struct LabExperimentStatus
    {
```

```
    public readonly ExperimentStatus statusReport;
    public readonly double minTimeToLive;
      /* guaranteed minimum remaining time (in hours) before this
         labExperimentID and associated data will be purged from the lab
         server */
  }

  public struct ExperimentStatus
  {
    public readonly int statusCode;
      /* Indicates the status of this experiment. 1 iff waiting in the
         execution queue, 2 iff currently running, 3 iff terminated
         normally, 4 iff terminated with errors (this includes
         cancellation by user in mid-execution), 5 iff cancelled by user
         before execution had begun, 6 iff unknown labExperimentID */
    public readonly WaitEstimate wait;
      /* see GetEffectiveQueueLength() */
    public readonly double estRuntime
      /* [OPTIONAL, <0 if not used] estimated runtime (in seconds) of
         this experiment */
    public readonly double estRemainingRuntime
      /* [OPTIONAL, <0 if not used] estimated remaining runtime (in
         seconds) of this experiment, if the experiment is currently
         running */
}
```

```
RetrieveResult:
  purpose: Retrieves the results from (or errors generated by) a previously
     submitted experiment.
  arguments:
    int experimentID
      /* a token that identifies the experiment */
  returns: ResultReport

    public struct ResultReport
    {
      public readonly int statusCode
```

```
           /* Indicates the status of this experiment. 1 iff waiting in the
               execution queue, 2 iff currently running, 3 iff terminated
               normally, 4 iff terminated with errors (this includes
               cancellation by user in mid-execution), 5 iff cancelled by user
               before execution had begun, 6 iff unknown labExperimentID */
        public readonly string experimentResult
           /* [REQUIRED if experimentStatus == 3, OPTIONAL if experimentStatus
               == 4] a opaque, domain-dependent set of experiment results */
        public readonly string labConfiguration
           /* opaque description of the lab configuration for the execution of
               this experiment */
        public readonly string xmlResultExtension
           /* [OPTIONAL, null if unused] a transparent XML string that helps
               to identify this experiment. Used for indexing and querying in
               generic components which cant understand the opaque
               experimentSpecification and experimentResults */
        public readonly string xmlBlobExtension
           /* [OPTIONAL, null if unused] a transparent XML string that helps
               to identify any blobs saved as part of this experiments
               results.*/
        public readonly string[] executionWarningMessages
           /* domain-dependent human-readable text containing non-fatal
               warnings about the experiment including runtime warnings*/
        public readonly string executionErrorMessage
           /* [REQUIRED if experimentStatus == 4] domain-dependent
               human-readable text describing why the experiment terminated
               abnormally including runtime errors */
     }

}
```

Appendix D

Ethics Documentation

The following Participant Information Statements and Participant Consent Forms were given to participants at the beginning of the lab session for participation consent according to University of Sydney Human Ethics requirements.

THE UNIVERSITY OF SYDNEY

School of Information Technology
Faculty of Engineering and IT

ABN 15 211 513 464

Professor David Lowe
Associate Dean (Education)

Room 454
J12 - The School of Information Technologies
The University of Sydney
NSW 2006 AUSTRALIA
Telephone: +61 2 9351 5653
Facsimile: +61 2 9351 3838
Email: david.lowe@sydney.edu.au
Web: http://www.sydney.edu.au/

Improving Laboratory Learning Outcomes - Remote Labs in Virtual Worlds

PARTICIPANT INFORMATION STATEMENT

(1) What is the study about?

You are invited to participate in a study aimed at improving laboratory learning outcomes.
We are looking at the effect that changing the laboratory environment can have on an identified laboratory learning outcome

By completing this laboratory activity you will be contributing to the data on the effect of manipulating a laboratory environment can have on what students learn from their labs.

(2) Who is carrying out the study?

The study is being conducted by Tania Machet and will form the basis for the degree of PhD at The University of Sydney under the supervision of Prof. David Lowe.

Prof. David Lowe is Chief Executive Officer of The Labshare Institute (TLI) which is involved with fostering the use of remotely accessible laboratory technologies within the education sector. TLI is not involved in this research.

(3) What does the study involve?

The study requires that you complete a laboratory activity in a virtual world including executing the lab and answering the assessment questions.

This lab activity investigates how radioactive radiation changes as a function of distance. It is conducted on real equipment which is accessed remotely through the virtual world. All the background information you need is available within the lab activity. The steps required to complete the lab are detailed within the virtual world and all the questions that must be answered on completion of the lab are supplied.

(4) How much time will the study take?

The minimum time that the laboratory will take is 40 minutes. It is expected most participants will spend 60 minutes on the lab activity.

(5) Can I withdraw from the study?

Being in this study is completely voluntary and you are not under any obligation to consent to submit your laboratory activity results to the study. Submitting a completed lab activity is an indication of your consent to participate in the study. You can withdraw any time prior to submitting your completed laboratory activity. Once you have submitted your responses, you will need to contact the researcher with your unique ID to withdraw your responses.

(6) Will anyone else know the results?

All aspects of the study, including results of the, will be strictly confidential and only the researchers will have access to information on participants.

A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

The results of the study may be used for future research into remote laboratories in virtual worlds. In such a case the information on participants will remain confidential, and participants will not be identifiable.

(7) Can I tell other people about the study?

Yes.

(8) What if I require further information about the study or my involvement in it?

When you have read this information, Tania Machet will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Tania Machet (PhD Student, School of IT, Faculty of Engineering and IT) at tmac2470@uni.sydney.edu.au

(9) What if I have a complaint or any concerns?

Any person with concerns or complaints about the conduct of a research study can contact The Manager, Human Ethics Administration, University of Sydney on +61 2 8627 8176 (Telephone); +61 2 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au (Email).

This information sheet is for you to keep

THE UNIVERSITY OF SYDNEY

School of Information Technology

Faculty of Engineering and IT

ABN 15 211 513 464

Professor David Lowe
Associate Dean (Education)

Room 454
J12 - The School of Information Technologies
The University of Sydney
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Facsimile: +61 2 9351 3838
Email: david.lowe@sydney.edu.au
Web: http://www.sydney.edu.au/

PARTICIPANT CONSENT FORM

I, ...[PRINT NAME], give consent to my participation in the research project.

TITLE: **Improving Laboratory Learning Outcomes - Remote Labs in Virtual Worlds**

In giving my consent I acknowledge that:

1. The procedures required for the project and the time involved have been explained to me, and any questions I have, have been answered to my satisfaction.

2. I've read the Participant Information Statement and have been given the opportunity to discuss the information and my involvement in the project with the researcher/s.

3. I understand that being in this study is completely voluntary – I am not under any obligation to consent.

4. I understand that my involvement is strictly confidential. I understand that any research data gathered from the results of the study may be published however no information about me will be used in any way that is identifiable.

5. I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher(s) or the University of Sydney now or in the future.

6. I consent to the data being collected in this project being used for future research into remote labs and virtual worlds, subject to ethics approval at the time.
   YES ☐
   NO ☐

....
Signature

....
Please PRINT name Date

Appendix E

Pretest Assessment

This pretest was given to each participant at the beginning of the lab session and each was required to complete and submit it before continuing with the lab activity.

Student ID:____

ID Number: PHYS

Pre-Test

This experiment measures how radiation varies at a distance from the source of radiation. We expect to find that the intensity of radiation is related to the distance from the radiation source by the INVERSE-SQUARE LAW. Before you begin, answer all the following questions on both sides of the paper.

1) Considering the radiation experiment you are about to complete, for each of the following statements, please select whether they are 'True' or 'False'?

	Statement	TRUE	FALSE
a.	The predicted values for the experiment will be incorrect as the model does not take into account background radiation from the environment.		
b.	Radiation from our computers or phones will affect the results so there will not be an inverse-square relationship		
c.	The theoretical prediction of an inverse-square relationship is an approximation only so results will not match exactly		
d.	Radioactive decay is random so the results will not match the inverse-square law exactly		
e.	Taking shorter measurement times will mean there is less chance of errors in the data so the results will show the inverse-square law better		
f.	The experiment equipment is far away so we cannot know if it is working correctly		
g.	Delay caused by situating an experiment remotely mean that the results will not be the same as if the equipment were in the lab		
h.	Running more trials of this experiment means there is more chance of errors occurring and results will be less accurate		
i.	Radiation absorbed by the environment in the remote laboratory will affect the results so we may not get exactly an inverse-square relationship		
j.	Incorrectly plotted data means the results may be incorrect		
k.	Inverse-square is a LAW so there should be no difference between the theoretical prediction and the measured value unless the experiment is incorrectly done		
l.	The inverse-square relationship we find will be applicable only to our radiation Source (Strontium-90). Other types of radioactive materials MAY have a different relationship.		
m.	Background radiation is taken into account in predicting the values so this will not affect our values at all.		
n.	If the experiment was performed in a vacuum chamber, the values would be the same.		
o.	If there was a *lead* shield *behind* the strontium source, the results would still show the inverse-square relationship.		
p.	If there was an *aluminium* panel *in front of* the strontium source, the results would not be affected.		

2) Select ‘True’ or ‘False’ for each of these phenomena or applications which you think would have the same relationship between ‘intensity’ and ‘distance from a source’ that we expect to find in our radiation experiment?

	Statement	TRUE	FALSE
a.	Intensity of light from the sun		
b.	The speed of a car in relationship to how hard the accelerator pedal is pushed		
c.	Level of radiation from an X-ray machine		
d.	Brightness of a perfectly focussed laser beam		
e.	Speed of a skipping rope		
f.	Strength of gravity		
g.	Height of waves in a pool when a stone is thrown in		
h.	Phone signal strength from a cell phone tower		
i.	Speed of a ball thrown straight		
j.	Volume of sound from a microphone		
k.	Turbulent flow from an aeroplane’s wing		

Appendix F

Laboratory Guide

This lab guide was given to each group of participants at the beginning of the lab session for reference on how to navigate the virtual world and control the remote laboratory.

Radiation Laboratory

Running the Laboratory

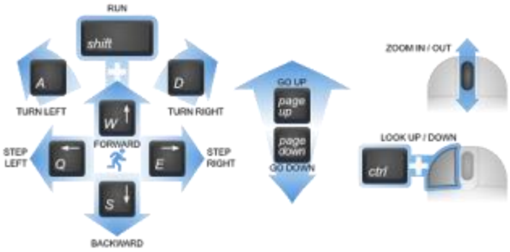
Tania Machet, PhD Student
University of Sydney
Semester 2 2014
tmac2470@uni.sydney.edu.au

Using Open Wonderland

This is an extract from the Open Wonderland tutorial. It can be found at https://sites.google.com/site/openwonderland/tutorials/learning-the-basics-tutorial#Navigation

Navigation

While you are learning to navigate, it is helpful to open the Navigation Reference guide. Select "Navigation Reference" from the Help menu:



Feel free to position the reference window anywhere you wish.

Now, click once on your character on the screen – this is your “avatar” - and try using the up and down arrow keys to move your avatar forward and backwards. The W and S keys will also move you forward and backwards. Now try turning right and left with either the right and left arrow keys, or the A and D keys. The scroll wheel on your mouse will zoom your view in and out. This is handy for getting an overview of the scene or for zooming in on a small detail. Holding down the Control key while dragging the mouse up and down is another way to look around at the scene. This allows you to look up at the sky or down at the ground.

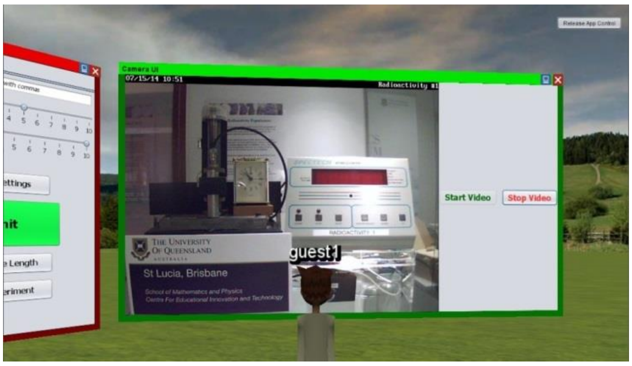
Use the up arrow or W key to move to a location with some open space. Experiment with the Q and E keys to step left and right. Now try running forward by holding down the up arrow key and the Shift key at the same time.

It's always fun to do things in the virtual world that you can't do in real life. To fly up into the sky for a birds-eye view of the world, first uncheck "Avatar Gravity Enabled" from the Tools menu. Now click on your avatar and then use the Page Up key to fly up. Once you're up in the air, use the right and left arrow keys to have a look around. You can also use the up arrow key to walk in the air. To fall back to earth, simply select "Avatar Gravity Enabled" again.

Selecting the experiment and camera objects

To use these applications and all others in Wonderland, right click on the object and select "Take Control" from the context menu.

The border of the window should turn green, indicating that you have control. You are now able to use the buttons and fields that are within the application.



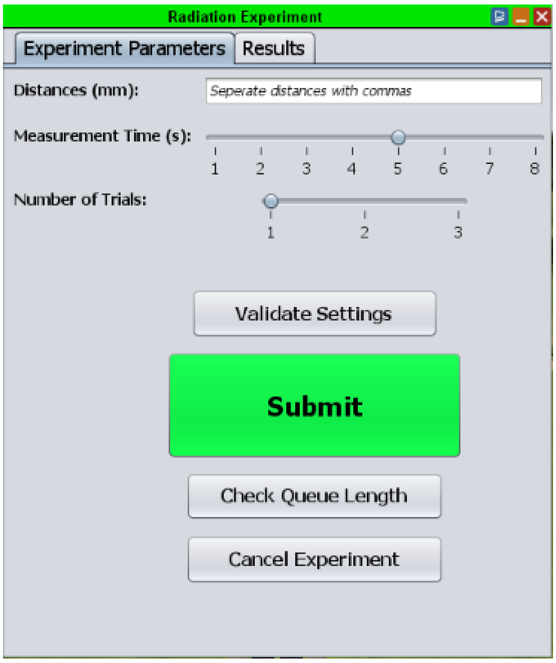
There is a “Release App Control” button that appears in the top right of the screen. Please note that while you have control of an application you will not be able to move around the world.

In order to move your avatar again, you will need to click on the "Release App Control" button in the upper right corner of your screen.

Running the lab

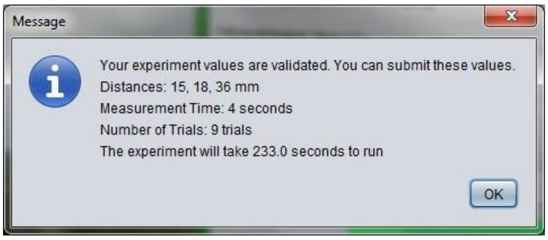
How to enter your parameters

1. Select the "Experiment" panel.
   In order to enter your experiment parameters, you must select the "Experiment" panel by right clicking on the border and selecting "Take control". The border of the experiment panel should now change from red to green.
2. Select the "Experiment" tab of the panel.
   In order to enter experiment data select the "Experiment" tab.
3. Enter the experiment parameters.
   a. The **distances** in millimetres from the strontium-90 source at which radiation can be measured. That is how far away from the source you would like to take the measurements.
      Criteria: Up to 6 values are permitted. The values should be separated by commas and be between 14mm and 95mm.
   b. The **measurement time** in seconds that each measurement of particle counts will last. That is how long the Geiger counter should count particles for each measurement distance. Select a value from the slider.
      Criteria: Select a value between 1 second and 8 seconds from the slider.
   c. The **number of trials** that will be conducted at the settings listed above. How many times the measurements at you specified distances should be repeated. Select a value from the slider.
      Criteria: Select a value between 1 trial and 3 trials from the slider

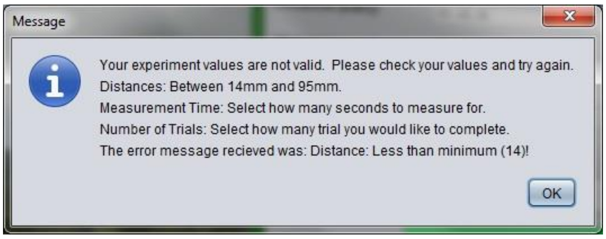


Validate your values

Once your values have been entered, verify them using the “Validate Settings” button. The result will show whether your values match the criteria or not. If your settings are not valid, the message will direct you to the problem.



```
Your experiment values are validated. You can submit these values.
Distances: 15, 18, 36 mm
Measurement Time: 4 seconds
Number of Trials: 9 trials
The experiment will take 233.0 seconds to run
```

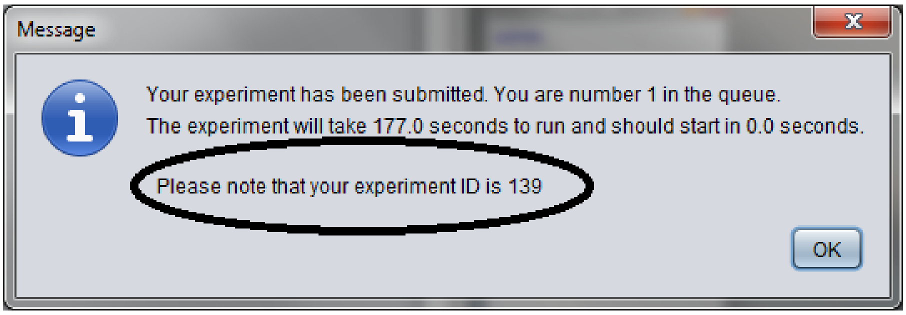


```
Your experiment values are not valid.  Please check your values and try again.
Distances: Between 14mm and 95mm.
Measurement Time: Select how many seconds to measure for.
Number of Trials: Select how many trial you would like to complete.
The error message recieved was: Distance: Less than minimum (14)!
```

Submit your experiment

To submit your experiment, select the “Submit” button. If the values are valid your experiment will be submitted and you will receive information regarding how long the queue to run your experiment is, as well as the running time for your experiment.

You will also get your experiment number – **please note this down**!



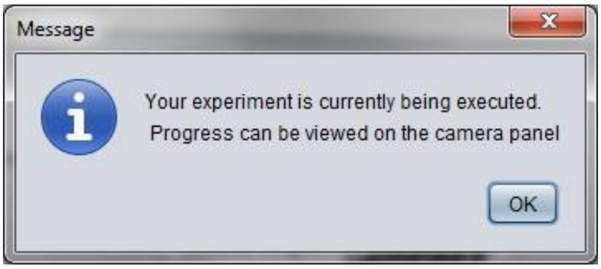
```
Your experiment has been submitted. You are number 1 in the queue.
The experiment will take 177.0 seconds to run and should start in 0.0 seconds.

Please note that your experiment ID is 139
```

Monitor your experiment

The progress of the experiment and wait time can be monitored. Within the Experiment panel, select the “Results” tab.

1. Enter the experiment ID that was received when submitting the experiment.
2. Select the “Check experiment progress” to determine the status of your experiment.
3. The message will indicate whether your experiment has been submitted or whether it is still in the queue.

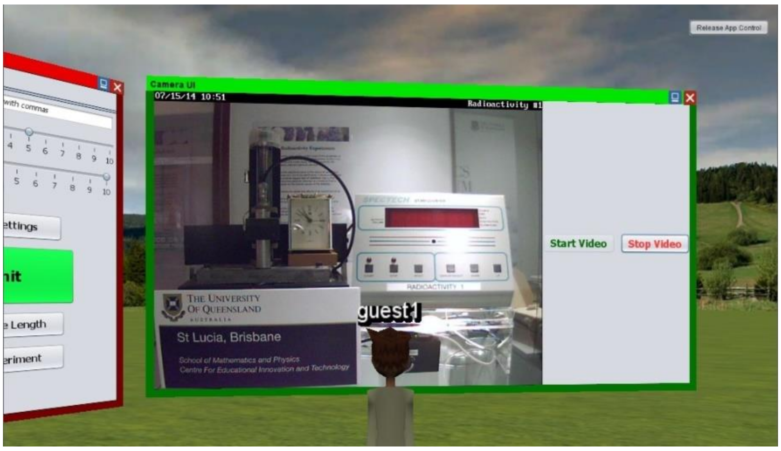

Your experiment is currently being executed.
Progress can be viewed on the camera panel

Watch equipment video

If you would like to view the equipment executing your experiment you need to:

1. Select “Release Control” on the top right of the world to release control of the experiment panel.

2. Select the “Camera UI” panel by right clicking and selecting “Take Control”.
3. Start the camera using the “Start Video” button.

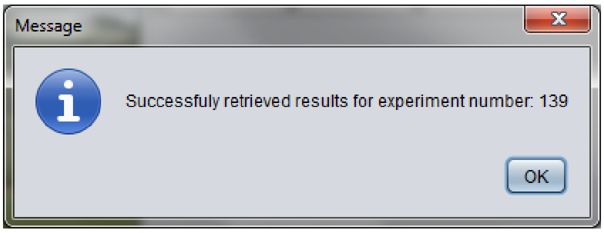


4. The Geiger counter indicator light will go on and the tube begin to move. Also readings should be visible on the counter.
5. Before releasing control be sure to select “Stop Video”.
6. Select “Release Control” on the top right of the world to release control of the experiment panel.

Retrieve your results

Once your experiment is ready, within the Experiment panel, select the “Results” tab.

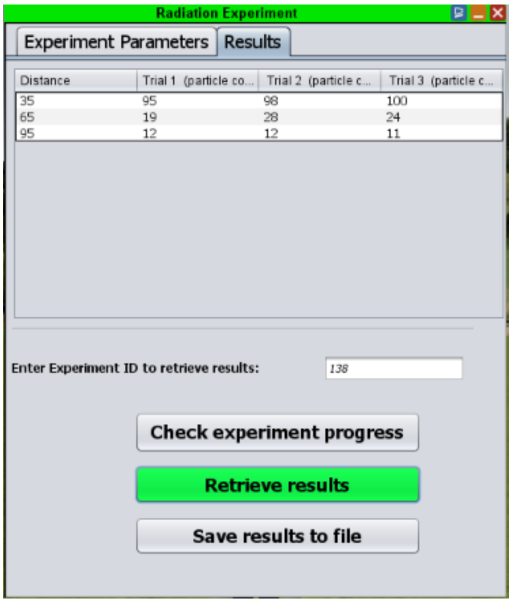
1. Enter the experiment ID that was received when submitting the experiment.
2. Select the “Retrieve results” button.



Message

Successfuly retrieved results for experiment number: 139

3. Your results should now be populated into the table.



Distance	Trial 1 (particle co...	Trial 2 (particle c...	Trial 3 (particle c...
35	95	98	100
65	19	28	24
95	12	12	11

Enter Experiment ID to retrieve results: 138

4. To save these results to file, please select the “Save results” tab.

Appendix G

Laboratory Assessment

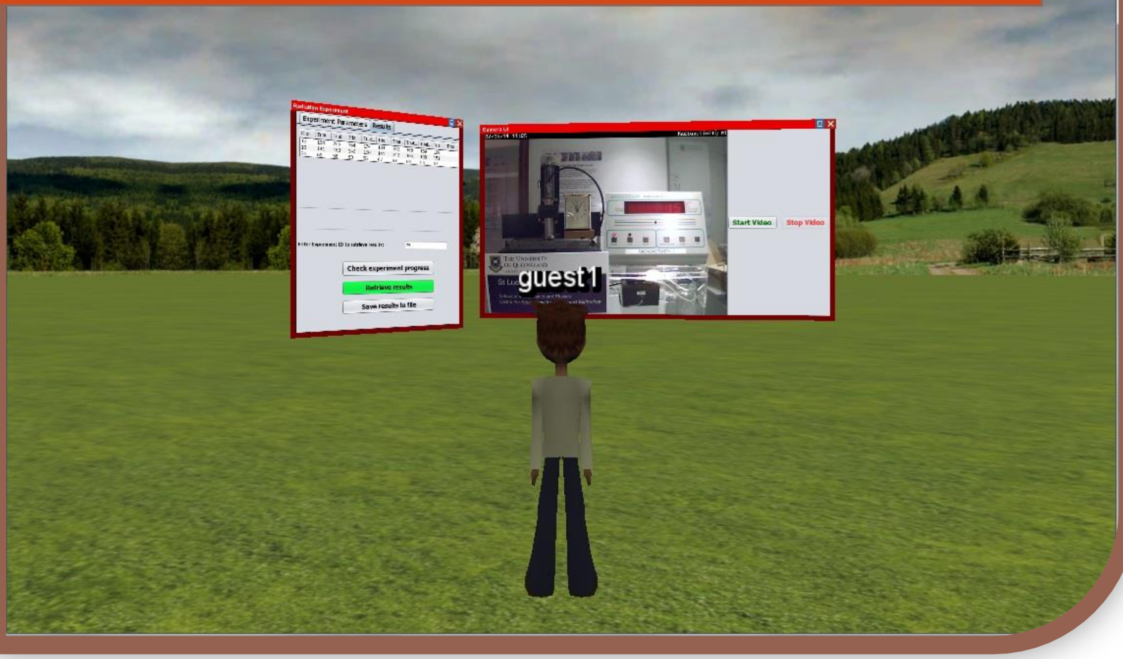
This student handout was given to each participant at the beginning of the lab session to be completed after the pretest had been done. It includes some background information as well as the laboratory execution and assessment tasks.

Student ID:________________________

ID Number: PHYS

Radiation Laboratory

Laboratory Activity



Tania Machet, PhD Student
University of Sydney
Semester 2 2014
tmac2470@uni.sydney.edu.au

Laboratory Activity

Learning Goals

On completion of this session you should:

1. Have experience designing an experiment.
2. Be familiar the inverse-square law for radiation intensity.

You will need to hand-in:

1. Participation consent form per person.
2. Completed pre-test per person.
3. This “Laboratory Activity” per person.
4. Research Questionnaire per group.

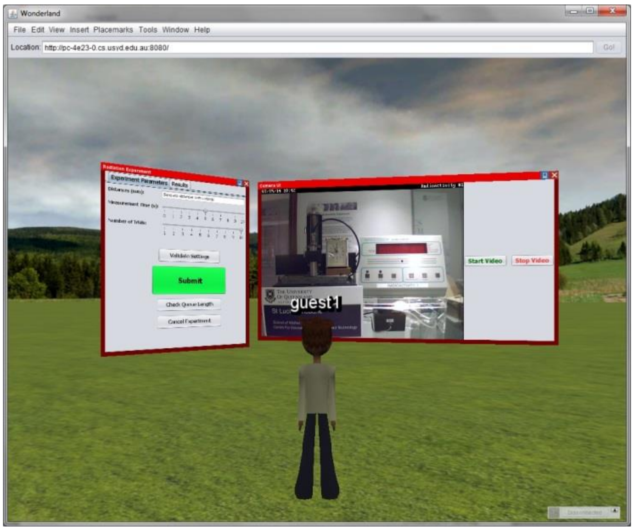
What is this lab about?

In this laboratory, you can investigate the intensity of radiation over distance using a radioactive strontium-90 sample and a Geiger counter, which is an instrument used to measure radioactive radiation.

The laboratory activity is done on real lab equipment that is housed at the University of Queensland. You can access the laboratory through the control panel, and see the equipment as the lab is carried out.

The laboratory activity involves verifying the inverse square law of radiation intensity.

For the lab today, you will be working in groups and accessing the laboratory control equipment through a virtual world using a character (or avatar). Each person must complete the laboratory assessment tasks individually.

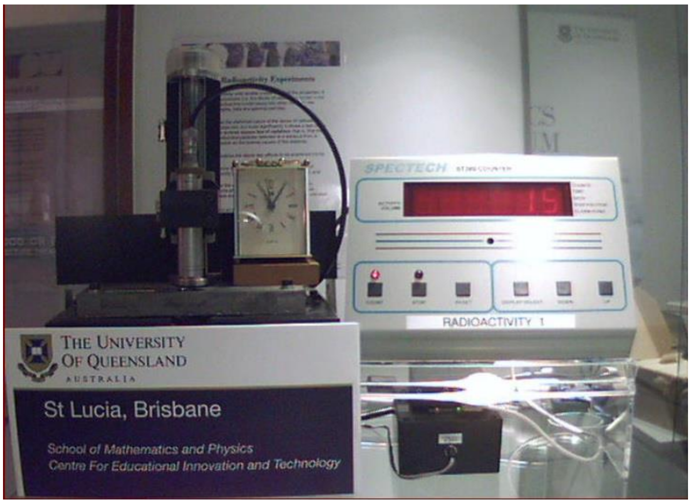


Location: http://pc-4e23-0.cs.usyd.edu.au:8080/

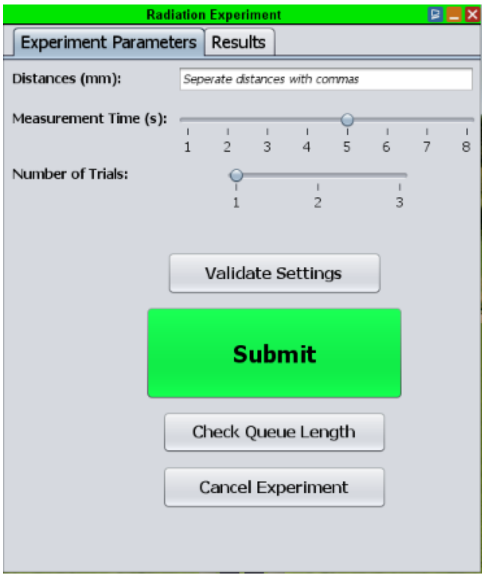
Laboratory equipment

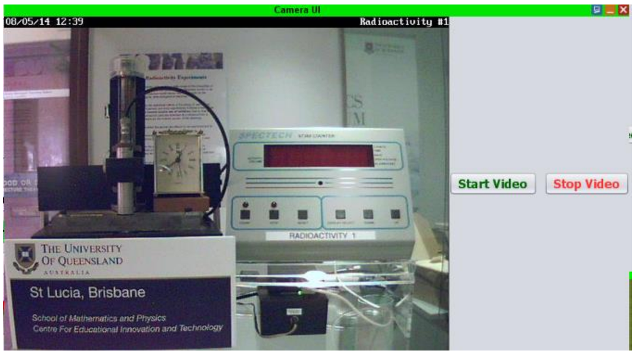
The following equipment is used in this laboratory:

1. A Geiger counter
2. A radioactive strontium-90 sample (under the metal plate)
3. Circuit board that connects the equipment to computers



The laboratory is controlled remotely through the interface seen in the virtual world and can be viewed on a camera panel.





Background information

(From Northwestern University - Office of STEM Education Partnerships, http://ilabs.sesp.northwestern.edu/iLabServiceBroker/)

What is radiation?

Radiation is the emission of energy from a source that travels through space in the form of waves or high-speed particles. Within the word radiation is the word "radiate", which means to spread out in all directions from a central point. Many types of energy radiate through space including light and heat.

What is strontium-90?

Strontium (chemical symbol Sr) is a silvery metal, and turns yellow quickly when exposed to air. Strontium in its natural form is not a radioactive element. However, strontium has 16 isotopes, which are other forms of strontium that have the same number of protons, but different numbers of neutrons. Twelve of the isotopes are radioactive, including strontium- 90. Strontium-90 emits beta particles as it decays. Strontium-90 has a half-life of 29.1 years, meaning it takes 29.1 years to for half of the radioactive atoms of a sample of strontium-90 to disintegrate. Strontium-90 is found in nature and often in waste from nuclear reactors. It is considered one of the more hazardous components of nuclear wastes

Inverse Square Law

(From http://en.wikipedia.org/wiki/Inverse-square_law)

In physics, an inverse-square law is any physical law stating that a specified physical quantity or intensity is inversely proportional to the square of the distance from the source of that physical quantity. In equation form:

$$\text{Intensity} \propto \frac{1}{\text{distance}^2}$$

Testing Radiation at a distance

Your goal is to execute the experiment in order to retrieve results indicating the how radiation varies at a distance.

This experiment measures particle count at a distance from the strontium-90 source. You can vary the distance away from the source you would like to take measurements, as well as how long to count for each measurement distance.

To execute the experiment, decide on the distances away from the source you want to take your measurements (between 14mm and 95mm) and for how long each measurement should count (between 1s and 8s). You can also specify how many times the experiment should be repeated (between 1 trial and 3 trials).

1. Each person MUST complete the pre-test you received with the lab activity and hand this in to the tutor before continuing with the experiment.

2. Execute the laboratory to investigate the relationship between intensity of radiation and distance from the source. **In your group, collect results by choosing parameters, executing the experiment.**

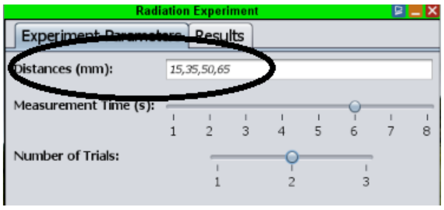
   The experiment is controlled using the Radiation Experiment control panel in the virtual world. To start please see the detailed notes on how to control your virtual world character (your avatar) and the control panel that have been provided.

   You can set:

   a) The distances in millimetres from the strontium-90 source at which radiation can be measured. Radiation is measured in units of "particle counts", which means the number of particles emitted from the strontium-90 sample that were counted by the Geiger counter.

      You can specify up to 6 different distances between 14mm and 95mm. Specify them in the radiation experiment control panel using commas to separate the distances.

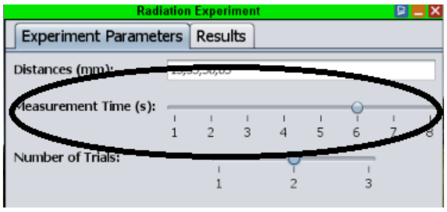
      For example if you chose to take measurements at 4 different distances of 15mm, 35mm, 50mm and 65mm you would enter: 15,35,50,65. **Please select your own values as a group.**



Distances (mm): 15,35,50,65

b) The measurement time in seconds that each measurement of particle counts will last. Select a value between 1 second and 8 seconds from the slider shown.

For example if you would like to take each measurement for 6 seconds, move the slider to 6. **Please select your own value as a group.**



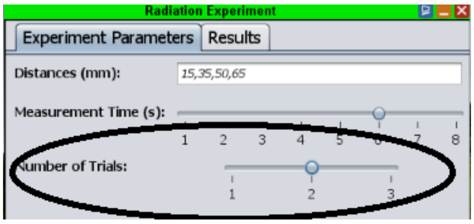
Distances (mm): 15,35,50,65

Measurement Time (s):

Number of Trials:

c) The number of trials that will be conducted at the settings defined. This is the number of times you would like to repeat the readings. Select a value between 1 trial and 3 trials on the slider shown.

For example if you would like to take 2 sets of readings, move the slider to 2. **Please select your own value as a group.**



Distances (mm): 15,35,50,65

Measurement Time (s):

Number of Trials:

Write the values your group used below:

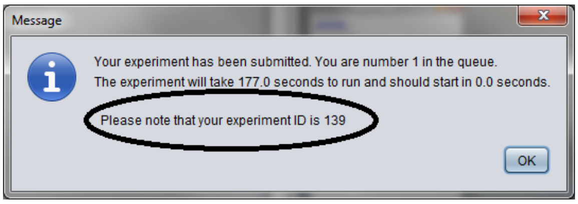
Distances: ____

Measurement Time: ____________________________________

Number of Trials: _____________________________________

3. “Validate” and “Submit” your experiment parameters. When you select “Submit” you will be given and experiment ID. **Note down your Experiment ID here – it is needed to retrieve your results.**

Experiment ID :________________________

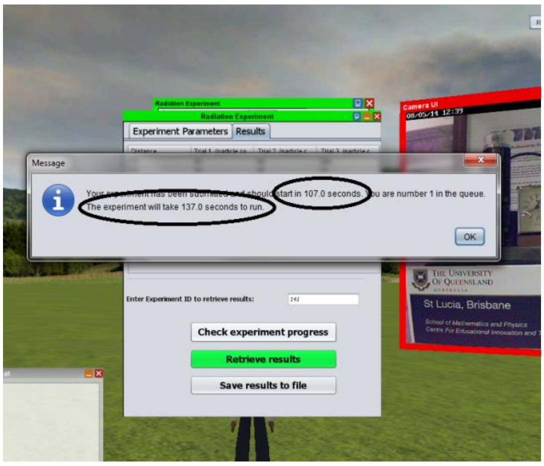


Your experiment has been submitted. You are number 1 in the queue.
The experiment will take 177.0 seconds to run and should start in 0.0 seconds.

Please note that your experiment ID is 139

DO NOT PROCEED UNTIL YOU HAVE NOTED DOWN YOUR EXPERIMENT ID!

After you submit your experiment you will be notified how long the experiment will take to run and how long the wait is before you run the experiment. You can check the progress of your experiment on the "Results" tab using the "Check experiment progress" button after specifying your experiment ID.



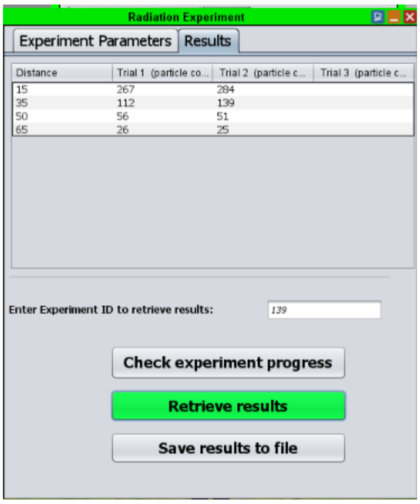
Your experiment has been submitted and should start in 107.0 seconds. You are number 1 in the queue.
The experiment will take 137.0 seconds to run.

Enter Experiment ID to retrieve results: 141

4. As a group, while you wait for your experiment to run, please complete the "Research Questionnaire" handed out. This can be completed later if your results are ready sooner.

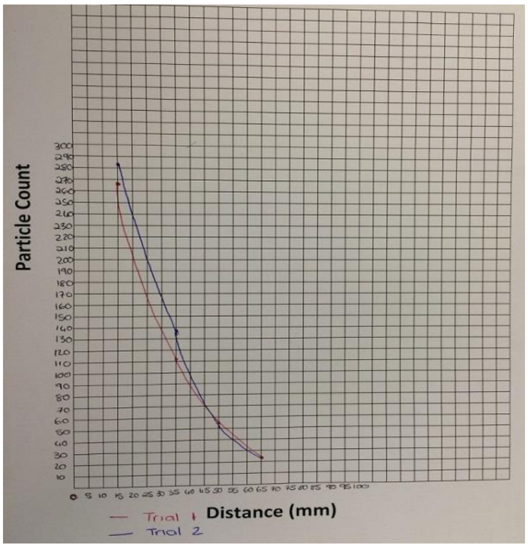
5. Once your experiment has run you will be able to view your results on the screen using the "Retrieve results button". These can be saved to file.

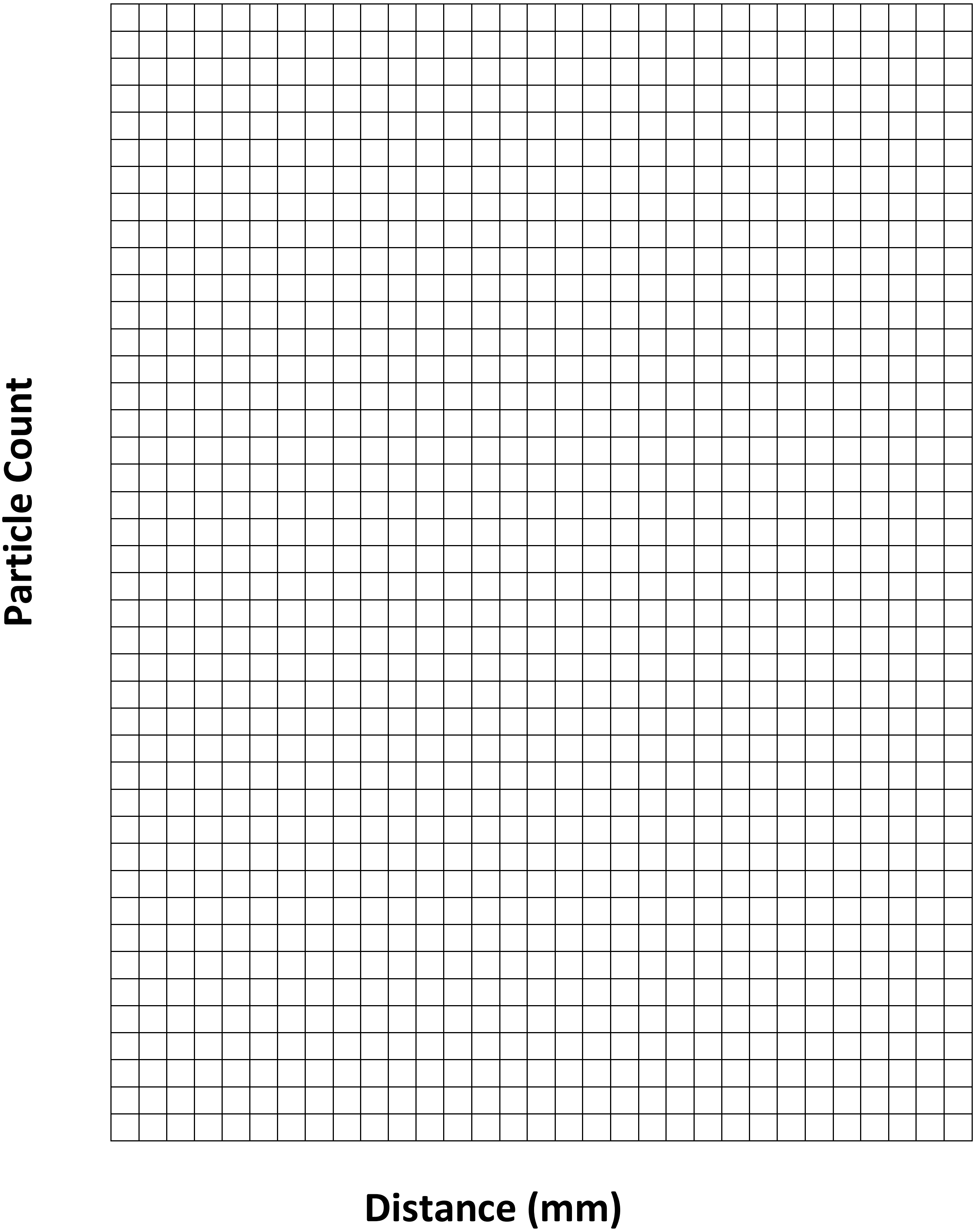
   Each person must plot the values on the graph paper provided and answer all the questions in "Laboratory Assessment" individually. In the example used above the following graph was obtained.



Distance	Trial 1 (particle co...	Trial 2 (particle c...	Trial 3 (particle c...
15	267	284	
35	112	139	
50	56	51	
65	26	25	

Enter Experiment ID to retrieve results: 139




Particle Count
Distance (mm)

Laboratory Assessment

EACH PERSON SHOULD ANSWER THESE QUESTIONS INDIVIDUALLY

1) Look at your data and graph.
   a) **Based on the data collected** how would you describe the relationship between the particle count and distance from the source? Why?

   b) Does your graph accurately illustrate theoretical relationship between radiation particle count and the distance from the strontim-90 source?

   c) How would you change your experiment to improve the fit between theoretical prediction and measured values?

2) Considering the radiation experiment you have just completed, for each of the following statements, please select whether they are ‘True’ or ‘False’?

	Statement	TRUE	FALSE
a.	The predicted values for the experiment will be incorrect as the model does not take into account background radiation from the environment.		
b.	Radiation from our computers or phones will affect the results so there will not be an inverse-square relationship		
c.	The theoretical prediction of an inverse-square relationship is an approximation only so results will not match exactly		
d.	Radioactive decay is random so the results will not match the inverse-square law exactly		
e.	Taking shorter measurement times will mean there is less chance of errors in the data so the results will show the inverse-square law better		
f.	The experiment equipment is far away so we cannot know if it is working correctly		
g.	Delay caused by situating an experiment remotely mean that the results will not be the same as if the equipment were in the lab		
h.	Running more trials of this experiment means there is more chance of errors occurring and results will be less accurate		
i.	Radiation absorbed by the environment in the remote laboratory will affect the results so we may not get exactly an inverse-square relationship		
j.	Incorrectly plotted data means the results may be incorrect		
k.	Inverse-square is a LAW so there should be no difference between the theoretical prediction and the measured value unless the experiment is incorrectly done		
l.	The inverse-square relationship we find will be applicable only to our radiation Source (Strontium-90). Other types of radioactive materials MAY have a different relationship.		
m.	Background radiation is taken into account in predicting the values so this will not affect our values at all.		
n.	If the experiment was performed in a vacuum chamber, the values would be the same.		
o.	If there was a *lead* shield *behind* the strontium source, the results would still show the inverse-square relationship.		
p.	If there was an *aluminium* panel *in front of* the strontium source, the results would not be affected.		

3) Select ‘True’ or ‘False’ for each of these phenomena or applications which you think would have the same relationship between ‘intensity’ and ‘distance from a source’ that we expect to find in our radiation experiment?

	Statement	TRUE	FALSE
a.	Intensity of light from the sun		
b.	The speed of a car in relationship to how hard the accelerator pedal is pushed		
c.	Level of radiation from an X-ray machine		
d.	Brightness of a perfectly focussed laser beam		
e.	Speed of a skipping rope		
f.	Strength of gravity		
g.	Height of waves in a pool when a stone is thrown in		
h.	Phone signal strength from a cell phone tower		
i.	Speed of a ball thrown straight		
j.	Volume of sound from a microphone		
k.	Turbulent flow from an aeroplane’s wing		

4) Choose one of these phenomena and suggest an experiment that could be used to investigate this.

Appendix H

Research Questionnaire Assessment

This research questionnaire was given to each group to complete as an optional submission at the end of the laboratory session.

Group ID Number:

Research Questionnaire

This information is to be used in analysing the results of this research.

Should you wish to contact the researcher with any questions or withdraw from the study at any time, please use the ID number on the top right of this page. The researchers contact details are: **Tania Machet: tmac2470@uni.sydney.edu.au**

1. How did using the remote laboratory in a virtual world affect your learning? Please rate each statement below.

	Statement	**Strongly disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly agree**
a.	In general, the virtual world was easy to use.					
b.	We enjoyed the laboratory activity more because of the virtual world.					
c.	We learnt more from this laboratory because it was in a virtual world.					
d.	We would like to see a more realistic world when doing the laboratory.					
e.	We found the virtual world a distraction when doing the laboratory activity					
f.	It is a good idea to use a remote laboratory for this laboratory activity.					
g.	It was difficult to understand the laboratory because the equipment was remote.					

2. If you have had difficulties executing this lab in terms of (a) navigating the virtual world and/or (b) controlling the remote laboratory, please describe them.

3. Do you think there was anything in this laboratory you learnt that you would not have learnt if it had been a traditional “hands-on” laboratory?

4. How did your experience change (either positively or negatively) because of the use of the Open Wonderland virtual world in this laboratory activity?

5. Would you like to do more laboratories in a virtual world?

6. Would you like to use more remote laboratories?

Appendix I

Raw Data

I.1 Computer information for lab

Table I.1 indicates which computers contained the contextual world and which the non-contextualised world, as well as the numbers of participants for each laboratory session.

Table I.1: List of laboratory computers and the corresponding treatment or control group assignation, along with number of participants in each group per session.

Computer	**Environment**	**Session 1**	**Session 2**
PHYS136	No Context	3	0
PHYS118	No Context	3	3
PHYS103	No Context	2	3
PHYS112	No Context	3	3
PHYS127	No Context	3	0
PHYS128	No Context	3	3
PHYS148	No Context	3	3
PHYS147	No Context	3	3
PHYS106	No Context	3	3
PHYS102	Research Complex Context	3	3
PHYS141	Research Complex Context	3	2
PHYS104	Research Complex Context	3	0
PHYS132	Research Complex Context	3	3
PHYS105	Research Complex Context	3	3
PHYS116	Research Complex Context	3	3
PHYS130	Research Complex Context	3	3
PHYS160	Research Complex Context	3	3
PHYS180	Research Complex Context	3	3

I.2 Excluded data

- Only one of PHYS132-1-1 and PHYS132-1-3 included
- Only one of PHYS160-2-1 and PHYS160-2-2 included
- Only one of PHYS116-2-1 and PHYS116-2-3 included
- Only one of PHYS132-2-2 and PHYS132-2-3 included
- Only one of PHYS102-1-2 and PHYS102-1-3 included
- Only one of PHYS112-1-1 and PHYS112-1-2 included
- Only one from PHYS104-1 included
- Only one from PHYS136-1 included
- Only one from PHYS147-1 included
- Only one from PHYS127-1 included
- Only one from PHYS141-1 included
- Only one from PHYS103-1 included
- The research questionnaire from group PHYS112-2 was excluded as it was not completed.

I.3 Pretest Information

Table I.2 illustrates the number of correct responses to each questions for all valid responses, for the treatment group, and for the control group.

I.4 Posttest Information

The results of the number of correct responses to each of questions in the laboratory activity posttest are summarised in the tables below for the modified data set. Table I.3 shows the number of correct responses to each of the repeated pretest question for all valid responses, for the treatment group, and for the control group. Table I.4 lists the marks received by participants for the longer response questions (that were not in the pretest).

Table I.2: Correct responses to pretest questions from 80 participants

Question Number	**Total Correct**	**Control Group**	**Treatment Group**
1a	53	20	33
1b	63	27	36
1c	57	23	34
1d	65	31	34
1e	58	29	29
1f	55	21	34
1g	51	23	28
1h	78	35	43
1i	58	27	31
1j	63	27	36
1k	51	21	30
1l	47	23	24
1m	37	16	21
1n	53	26	27
1o	49	23	26
1p	59	26	33
2a	78	35	43
2b	67	33	34
2c	74	35	39
2d	17	9	8
2e	72	32	40
2f	47	20	27
2g	48	19	29
2h	71	33	38
2i	56	25	31
2j	57	25	32
2k	56	25	31

Table I.3: Correct answers to repeated pretest questions from 80 participants

Question Number	Total Correct	Control Group	Treatment Group
2a	43	19	24
2b	70	30	40
2c	52	23	29
2d	61	29	32
2e	52	28	24
2f	41	17	24
2g	61	25	36
2h	68	33	35
2i	54	22	32
2j	53	20	33
2k	47	20	27
2l	51	24	27
2m	39	19	20
2n	57	27	30
2o	44	23	21
2p	56	25	31
3a	79	36	43
3b	70	35	35
3c	74	36	38
3d	22	12	10
3e	72	32	40
3f	55	23	32
3g	49	22	27
3h	75	34	41
3i	58	27	31
3j	57	19	38
3k	59	29	30

Table I.4: Marks awarded for posttest long response questions (not repeated from the pretest).

Question Number	Total Correct	Control Group	Treatment Group
1a	108	43	65
1b	96	44	52
1c	119	60	59
4	112	54	58

I.5 Research Questionnaire Information

The following tables include the comments made by participants for the research questionnaire open answers for those responses that were completed. Table I.5 shows the comments for all valid responses for the treatment group, Table I.6 shows those for the control group.

Table I.5: Treatment Group responses for research questionnaire long response questions.

Group	Q2.	Q3.	Q4.	Q5.	Q6.
PHYS160-1	The system was laggy	The set up/ equipment	Positively, we advance use of technology	No, the system was too slow and the technical difficulties made it hard to complete the work	No
PHYS141-2	No. But navigating the avatar seemed pointless. The camera does not seem to function well/ show the experiment being conducted	No	Neutral	No, not really. Prefer hands on equipment as there is more to learn from such	No
PHYS132-2	1. Movement not smooth 2. The virtual lab unneccessarily far	No	Not having to move (positive) It does not look realistic (negative)	No	No
PHYS105-1	The instruction wasn't clear when controlling the avatar. Sometimes it was laggy	It was less time consuming therefore the results were faster to obtain	Negatively since the program was slow and difficult to use	No thank you. I prefer real life hands on practicals more	No thank you. One experience is enough but once in a while is OK
PHYS105-2		No	Positive: gives a different perspective of experiment, less physical work, no human error, no safety hazards, no cleaning needed to be done	Maybe, depends on experiment	Maybe, depends on experiment
PHYS116-2	N/A	Not really	It was nice to have bit of a change and do something a little different	Yes. Unless we have to wait too long. This lab could have been split in 2	Neutral
PHYS132-1	No difficulties	No	Positively	Yes	Yes
PHYS160-2	No difficulties	No	More convenient to obtain particle count	Yes	Yes
PHYS130-1	Just weren't sure how to use parameter section	No	Want it in all our labs	Yes	Yes
PHYS180-1	It froze a few times	No	Positively: takes less time, very organized	Yes	Yes

Table I.6: Control Group responses for research questionnaire long response questions.

Group	Q2.	Q3.	Q4.	Q5.	Q6.
PHYS148-2	3 of us. It was easy so no problems	3 of us. No We would learn more with traditional 'hands-on' laboratory	2 of us say negatively. Not learning as much. 1 of us say positively	No - 3 of us	No - 3 of us
PHYS147-1	No difficulties	We would have learned more if it was a hands on laboratory	Nothing changed	Sorry no	No
PHYS128-2	We had no difficulties	No	Our group prefers hands on experiments	No	No
PHYS106-2	Figuring out how to use the program. Following instructions	No	Not very interesting as it wasn't a real life experiment	No	No
PHYS147-2		No	Less experimental errors	No because we would like to set the experiment up by ourselves in the real world. In the real world, we think we will have a better understanding of how the results are gained	No
PHYS128-1	The main difficulty for our group was trying to understand and interpret the results through the live camera as the experiment was being conducted	No, not really	Our experience changed positively because it was interesting to see the operation of a virtual world	No, its more educational to have a balance and get to have hands on experience	No, same reason as above
PHYS103-2	Purpose of video, lagging	No	It was more engaging but it was difficult to get used to the controls	No	No
PHYS102-1	I did not have difficulties. It was quite straight forward and easy to control	No	There was no change, probably more fun	Yes	Yes
PHYS118-2	Nice interface, easy to understand and straightforward	Not really, both would have yielded similar outcomes	Good for experiments that involve radiation, reduces risks. No hands on experience which can be helpful tool for some students	Yes	Yes
PHYS118-1	How do you use the camera? This was really the only problem - everything else was fine	No	Did not experience much changes	Yes, it is fun. Time efficient as well	No, it is better we can also visit the labs to see the setting
PHYS136-1	It was simple, easy to understand	No, it was faster	It was more efficient	Yes	Yes
PHYS106-1		No	Learnt easy convenience of technology	Occassionally	It seems more simple so yes
PHYS112-1	Took a while to work out how to move between windows but when showed by tutor, very easy	No	Positively - more interactive although wish avatar could move arms & dance	Yes	Yes